The Dissertation Committee for Soon Wook Han Certifies that this is the approved version of the following dissertation:

THE ROLE OF TEACHER EFFICACY IN THE DEVELOPMENT OF PEDAGOGICAL CONTENT KNOWLEDGE AMONG EXPERIENCED SCIENCE TEACHERS

Committee:

James P. Barulfaldi, Supervisor

Cesar Delgado

Mary E. Hobbs

Jill A. Marshall

Charles T. Sherron

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Soon Wook Han, B.A.; M.Ed.

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THE ROLE OF TEACHER EFFICACY IN THE DEVELOPMENT OF PEDAGOGICAL CONTENT KNOWLEDGE AMONG EXPERIENCED SCIENCE TEACHERS

Soon Wook Han, Ph.D.

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Supervisor: James P. Barufaldi

ABSTRACT

The purpose of this qualitative study was to examine the developmental process of pedagogical content knowledge (PCK) among experienced science teachers. Since teaching is a "learned profession" (Shulman, 1987) centered on a unique set of knowledge, PCK becomes a critical avenue to investigating the roots of effective teaching. Research suggests that PCK develops and grows through classroom practice (Lederman, Gess-Newsome, & Latz, 1994; van Driel, Verloop, & de Vos, 1998; van Driel, De Jong, & Verloop, 2002). In addition, teacher efficacy has been argued to be an "affective affiliate" of PCK (Park, 2007) indicating an association between empowered teachers and knowledge growth. Therefore, this study examined the role of teacher efficacy in sustaining PCK growth among experienced teachers to better comprehend the mechanism of action of classroom teaching experience.

This collective case study involved three experienced high school science teachers who have been teaching for at least eight years. Data collection involved the use of

classroom observations coupled with teacher interviews. In addition, instruments used in data collection included the use of the CoRe/PaPeRs (Content Representation/Pedagogical and Professional Experience Repertoires) template for validating PCK episodes (Loughran, Mulhall, & Berry, 2004; Loughran, Berry, & Mulhall, 2006) as well as the Science Teaching Efficacy Belief Instrument (STEBI) that was used to evaluate efficacy levels. Data analysis indicated teacher efficacy plays a pivotal role in developing PCK through a system of validation and evaluation of the teacher's cognitive belief structure. Furthermore, it was determined that as teachers gain classroom teaching experience, their sustained PCK growth is the result of increasing their knowledge of student understanding.

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CHAPTER 1: INTRODUCTION

Statement of Problem

Successful teaching is a multifaceted endeavor that entails the proper bridging between the knowledge base of teachers and student learning. The requisite skills for teachers to establish a sound and effective practice lies not only in possessing a fundamental knowledge of the subject matter but having the expertise to teach such knowledge to students in a meaningful fashion. Since "knowledgeable, skillful teachers form the bedrock of good schools" (Noyce, 2006, p. 36), the essential assets teachers need to optimize learning in the classroom are grounded on the principles of teacher knowledge that are tied to recognizing the cognitive characteristics of students.

At its core, the teaching profession is centered on conveying knowledge from teacher to student. However, teaching encompasses more than the conveying of content knowledge, it is an intricate task that requires teachers to not only be versed in content knowledge but be capable of delivering such knowledge in a way that can be comprehended by students. Such creativity and resourcefulness by skillful teachers in explaining and demonstrating subject matter to students defines the teacher knowledge skillset that is an inherent requirement of effective teaching.

Traditionally, most teachers develop their practice by harking back to their experiences as a student and the manner in which they were taught. This "apprenticeship of observation" (Lortie, 1975) has served as the template for teacher development for many educators. However, such a skewed version of teacher training has not been an effective vehicle for developing educators since prospective teachers tend to fall back on their years of being a student which would lead to them being "intuitive and imitative rather than explicit and analytical" (Lortie, 1975, p. 62).

As a result of the passage of the No Child Left Behind Act (NCLB) of 2002, the proliferation of testing has also brought into focus the inadequacies of the educational system in raising student achievement levels. Underperforming student test scores have, therefore, been the primary impetus in pushing through school reform (Hewson, 2007) particularly in the arena of teacher quality and effectiveness. As a result of NCLB and the ever escalating role of standardized testing, increased pressure to raise student achievement levels has brought the term "qualified teacher" into the vernacular. According to the NCLB legislation, a highly qualified teacher possesses three basic requirements: teacher certification, mastery of content knowledge in a subject area, and a bachelor's degree. Thus knowledgeable and skillful teachers in the classroom would provide the impetus needed to rectify the problem of low student achievement in schools across the country. However, the solution of producing highly qualified teachers, when probed, is a complex circumstance that must first start with teachers developing an appropriate grasp of teacher knowledge.

Like other professions, teaching is centered on a unique set of knowledge. Such a knowledge base for teaching is "a codified or codifiable aggregation of knowledge, skill, understanding, and technology, of ethics and disposition, of collective responsibility as well as a means for representing and communicating it" (Shulman, 1987, p. 7). Seven categories of the teacher knowledge base have been outlined that serve as the basis of teacher understanding:

(1) Content knowledge;
(2) General pedagogical knowledge, with special reference to those broad principles and strategies of classroom management and organization that appear to transcend subject matter;
(3) Curriculum knowledge, with particular grasp of the materials and programs that at serve as "tools of the trade" for teachers;
(4) Pedagogical content knowledge, that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding;
(5) Knowledge of learners and their characteristics;
(6) Knowledge of educational contexts, ranging from the workings of the Group or classroom, the governance and financing of school districts, to the character of communities and cultures;
(7) Knowledge of educational ends, purposes, and values, and their philosophical and historical grounds (Shulman, 1987, p.8).

Of the categories listed, pedagogical content knowledge (PCK) is the central component of the teacher knowledge base that warrants closer examination since it affects "classroom practice and [is] modified and influenced by practice" (Turner-Bisset, 1999, p. 42).

The construct of PCK is grounded on the premise of knowledge transformation tailored to the specific needs of the students. It is the defining characteristic of a teacher's practice that combines the aggregate teacher knowledge base that is germane to specific learning conditions. Thus, PCK's growing influence and its evolving nature in classroom practice highlights its critical nature in not only student learning but teacher development. In addition, the significance of teacher knowledge, particularly that of PCK, is becoming increasingly relevant in the present educational climate as a result of the accountability and scrutiny placed on student achievement.

Because teaching is a cognitive endeavor, teachers who display a competent grasp of the various components of the knowledge base do not necessarily warrant being considered proficient in the classroom. This is particularly evident in the case of PCK, an inherently dynamic component of the knowledge base, that results not from combining the conglomerate parts of teacher knowledge but from an "active process" (Cochran, DeRuiter, & King, 1993) that get cognitively transformed as the situation warrants in the classroom.

Since the development of PCK forms the underpinning of teacher development, its role in the model of teacher cognition must be envisaged as critical. Teaching and learning are considered to be a "social activity," a type of "human social construction [in which] people have to do something to get it started, to enact one kind of event after another, and to bring it to a close" (Lemke, 1990, p.2). In addition, Posner, Strike, Hewson, and Gertzog's (1982) theory of conceptual change involves the transformation of an individual's cognitive belief structure when incorporating new knowledge. This enhances the idea that teaching, specifically PCK, entails a transformation of beliefs about content knowledge and pedagogy that can be tailored to student learning.

The role of cognition, therefore, adds another dimension to the complexity of the PCK framework and as a result, must be explored to better understand the nature and development of PCK. This feature is represented by the concept of teacher empowerment. Like teacher knowledge, teacher empowerment harbors a multidimensional component whereby teacher efficacy is most important. Defined as the "teachers' belief or conviction that they can influence how well students learn, even those who may be considered difficult or unmotivated" (Guskey & Passaro, 1994, p. 628), teacher efficacy and its relationship to teacher development must be examined to help illuminate the origins and development of PCK.

Purpose of Study

Because of its relevance in forging more effective teachers, the development of PCK has been a key focal point in educational research since its introduction over twenty five years ago by Shulman (1986, 1987). To this end, a study of the relationship between the development of PCK and teacher efficacy will allow a fuller understanding of the development of skillful educators. In the ever evolving landscape of educational reform where the call for more effective teaching is continuing to grow, examining the nature of teacher knowledge will be needed to help educators become more effective teachers in the classroom.

The purpose of this study is centered on the interrelationship between PCK and teacher efficacy and how this association helps cultivate the development of the teacher knowledge base, particularly PCK. Furthermore, because classroom experience has the greatest influence on PCK development (Lederman, Gess-Newsome, & Latz, 1994; van Driel, Verloop, & de Vos, 1998; van Driel, De Jong, & Verloop, 2002), it is generally assumed that a direct correlation between classroom teaching experience and the level of PCK exists. Experienced teachers who have taught for a significant number of years, mostly at the same school, still undergo their PCK development, albeit at different and various levels. Nevertheless, growth still exists for these seasoned teachers. The greater question therefore lies in the influence behind the growth of PCK in experienced teachers.

Furthermore, it has been proposed (Park, 2007) that an association exists between teacher efficacy and the development of PCK. This relationship needs to be explored further to help elucidate key factors that drive the growth of PCK. The development of an experienced teacher, as he/she encounters differing teaching conditions every year was explored. Because of the vital roles played by both teacher efficacy and teacher knowledge in their influence on skillful teaching, this qualitative study explored the contingencies that arise, through the lens of the model of PCK and teacher efficacy development, as the seasoned teacher professionally and personally learns and grows in the classroom. By gaining a better understanding of this process of learning and growth, this case based study delved into how individual teachers, with years of experience, come to realize their teaching potential as they gain an insight into their practice due to becoming better aware of their teaching environment.

Research Questions

The central premise for this study aimed to delineate the interrelationships between PCK and science teacher efficacy and how they help enhance the development of PCK. Research has shown that knowledge development is highly specialized and individualistic (Friedrichsen et al., 2009; Magnusson, Krajcik, & Borko, 1999) as teachers gain classroom teaching experience. Furthermore, the role of teacher empowerment, especially teacher efficacy, could provide an immense contribution to better understand how teachers develop their own PCK. Recent research (Park, 2007; Park & Oliver, 2008) has demonstrated a connection between teacher efficacy and PCK growth since "teachers [who] believe their [in] capability to execute their PCK effectively…will be more likely to [have PCK] be enacted in the classrooms" (Park, 2007, p. 780). This brings into play the notion that "teacher efficacy is an affective affiliate of PCK" (Park, 2007, p. 773).

Thus the primary research questions that need to be addressed from this study are the following:

1. Does PCK evolve over time among experienced science teachers? If so, how? And how does classroom experience contribute to PCK development?
2. Does teacher efficacy among science teachers enhance the development of PCK? If so, how?

Significance of Study

By better detailing the progress of PCK growth in teachers and its relationship to teacher efficacy, professional development opportunities can be fashioned to help teachers harness their cognitive abilities to not only raise their efficacy levels but help in gaining and improving their PCK. Because professional development programs that are tailored to student learning are critical assets in forging effective teaching (Loucks-Horsley, Love, Stiles, Mundry, & Hewson, 2003), programs that can be centered on raising awareness of teacher efficacy and its consequences on building a solid teacher knowledge base can evolve the field of teacher education. A design framework for teacher learning based on the need for teachers to have “ownership and feel competent to create appropriate learning environments for their students” (Loucks-Horsley et al., p. 14) is the central motif of the relationship between PCK and teacher efficacy and, as such, becomes an important avenue for teacher education programs.

Teaching is a complex and cognitive endeavor that is highly individualized and context specific. Loughran, Berry, and Mulhall (2006) write that “PCK is the knowledge that teachers develop over time, and through experience, about how to teach particular content in particular ways in order to lead to enhanced student understanding” (p. 9). Gaining more insight into the relationship between knowledge building and teacher empowerment can potentially help in structuring professional development programs that can assist teachers become empowered enough to realize their capacity for PCK development.

Limitations of Study

The main limitation of this study was the fact that PCK among teachers is highly specific and individualized. Since the landscape of PCK is context specific, varying degrees of PCK can arise from different teachers depending on the circumstances of the learning environment. Therefore, teachers with varying amounts of teaching experience coupled with the diverse setting of classrooms today can limit the scope of understanding the very nature of knowledge building. The scope of this qualitative study was therefore dependent on the context of these case studies since each study describes the growth of individual teachers who possess different backgrounds and conceptions of learning.

However, each individual case provided a generalized picture of the phenomena of teacher knowledge and empowerment by rooting out the source of each facet of teacher development. By constructing a rich and descriptive picture of the relationship between teacher knowledge and empowered teachers, it is hoped that the understanding from this case study can provide another avenue to help demarcate and highlight the paramount role PCK and teacher efficacy have in the learning process of students.

Another pertinent limiting factor involved in this study was the choice of participating teachers. Teacher recruitment was a simplified process in which the principal asked science teachers if they wanted to participate in the study. Out of more than 20 science teachers, four responded positively. Initially, all four teachers were selected for the study but during data collection, the decision to drop one teacher from the group was made due to the teacher not completing assigned tasks (CoRe/PaPeRs) as well as extended absences due to his coaching duties. Furthermore, of the three remaining teachers, one teacher (biology) did not have a permanent classroom so she would teach in a different classroom for all of her classes.

In regards to the participating teachers, a limiting factor encountered was the use of their self-reported retrospectives, collected during teacher interviews, about their teaching practices. The validity of such retrospectives can be questioned due to the subjective nature teachers can view themselves. Teachers can, for instance, either forget or alter key events in their teaching careers in self-reports that could have been pertinent for the study. However, such retrospectives became feasible due to the time constraints faced during data collection.

CHAPTER 2: LITERATURE REVIEW

Overview

Since teachers play a pivotal role in shaping the learning environment for students, understanding the professional knowledge base of teachers constitutes an important facet of teacher education that can impact learning in the classroom. Research on teacher education has revolved around the quest to, ultimately, improve student learning in the classroom. Over the years, the field has shifted from the behavioral paradigm of rooting out specific teacher behavioral patterns associated with student achievement outcomes to now delineating the role of teacher knowledge and how a specific knowledge base can impact teaching practices. Thus the early studies of process-product research that dealt with searching for specific patterns related to effective teaching with the teacher being an independent variable (Good & Grouws, 1977) has evolved into learning more about what the teacher knows and should know in order to become a competent educator.

The intricate relationship between teacher and student has always defined the essence of education. In its most basic form, education has revolved around the exchange of knowledge and skills from the teacher to the student in a manner that is most conducive for learning. But as the educational environment become entrenched in the standards movement where academic achievement has been gauged by standardized testing, greater calls and pressure to increase student learning have been the primary focus of educational reform movements. One area that has been receiving greater attention has been to determine the role of the teacher and its impact on learning in the classroom. Darling-Hammond (1998) writes that “what teachers know and do is one of the most important influences on what students learn” (p. 6) and it is this critical aspect of the educational milieu, teacher knowledge and teacher learning, that needs to be examined to better comprehend the nature of learning and knowledge and the paramount role teachers play in the learning process.

Skillful teachers are individuals who not only are versed in content knowledge but also are able to convert such knowledge into learning opportunities for students. Therefore, teacher learning and the manner in which teachers acquire knowledge becomes an important arena of education research that needs further examination. Shulman (1987) writes that “teaching is, essentially, a learned profession” and that teachers must come to understand the “structures of subject matter, the principles of conceptual organization, and the principles of inquiry” (p. 9). Such attributes require the teacher to comprehend not only knowledge about teaching and subject matter but be able to transform his/her belief structures about teaching. Furthermore, nuances and manifestations of teacher learning include notions of efficacy as helping in the practice of teaching. The successful teacher thus understands the complexity of the learning process by bridging knowledge with experience not only to spark curiosity among the students but also to teach in a manner that enhances motivation and development.

Theoretical Framework

The theoretical framework for the concept of teacher learning and the acquisition of knowledge is grounded on a social-constructivist model (Driver, Asoko, Leach, Mortimer, & Scott, 1994; Howe & Stubbs, 1997) centered on the concept that teachers belong to a community of active and life-long learners. In addition, cognitive theories (Green, 1971; Borko & Putman, 1996; Putman & Borko, 2000) that situate beliefs and attitudes towards learning are also paramount in delineating the learning process. Central to this premise is the role of experience and culture in learning (Dewey, 1916; Vygotsky, 1987) and how such learning becomes dependent on molding and changing the belief structures of individuals. The constructivist model of learning is predicated on the assumption that knowledge is not transmitted passively but is actively constructed and that "understanding is situated and context bound, and social interactions are deeply intertwined with the development of tools for understanding" (Howe & Stubbs, 1997, p. 152). Furthermore, the sociocultural model hinges on "social interaction among and between people as a primary source of knowledge that cannot be gained in isolation from other people" (Howe & Stubbs, 1997, p. 171). Knowledge is a dynamic characteristic of the human condition that is actively created through individual actions and experiences "heavily influenced by an individual's existing knowledge and beliefs and is situated in particular contexts" (Borko & Putman, 1996, p. 675).

For Vygotsky (1987, 1994), social interactions and the use of language are critical aspects of culture that aids in the conceptual understanding of knowledge. His interpretation of culture that emerges through "scientific concepts" (Vygotsky 1987) is a type of experience that students come to realize through discourse. Thus by generating and using communication in a social environment, an experience is generated for the learner to actively seek out knowledge. Glassman (2001), in interpreting Vygotsky, writes that "human inquiry is embedded within culture, which is embedded within social history" (p. 3). The social relationships that exist among individuals, therefore, are able to generate the necessary tools for learning. This sociocultural theory constitutes the foundation of experience that is so critical for understanding to be fruitful.

Dewey (1916) proposes an analogous argument by stating that "education is a fostering, a nurturing, a cultivating, process" (p. 10). Learning must not be relegated to training individuals, but rather be part of a social structure that involves effective communication between teacher and student. He writes that the "use of language to convey and acquire ideas is an extension and refinement of the principle that things gain meaning by being used in a shared experience or joint action" (p. 16). The social interactions and the ensuing experience that comes with it are central to the learning process. It is only by this route that individuals are able to fully develop and grow to be productive citizens of society.

The foundation of Dewey's theories on education rests on the premise of experience and how that can be channeled into a more effective form of teaching and learning. He states that the "inclination to learn from life itself and to make the conditions of life such that all will learn in the process of living" (p. 51) be the essential purpose of learning. The following statement encapsulates Dewey's standing on the nature of experience:

> Experience as trying involves change, but change is meaningless transition unless it is consciously connected with the return wave of consequences which flow from it. When an activity is continued into the undergoing of consequences, when the change made by action is reflected back into a change made in use, the mere flux is loaded with significance. We learn something. (p. 139)

The connection between action and consequence therefore becomes paramount in the learning process because the individual is physically able to witness the direct result of his/her actions, which causes the act of exploration to incite the person's curiosity and wonder. This congruent feature of active constructivism, is the hallmark of discovery learning. Learning as well as teaching must not be unidirectional, rather it is the interaction between teacher and student that cements knowledge.

The salient points of the process of learning from both Dewey and Vygotsky denote a merging of sociocultural as well as constructivist perspectives that forms the framework for understanding teacher learning and knowledge. However, the study of belief systems and their integration into the learning process becomes paramount if successful knowledge building is to take place. Posner et al. (1982) posit the existence of two phases of conceptual change, assimilation and accommodation, responsible for changing the belief structures of teachers. Assimilation, a process that describes how individuals "use existing concepts to deal with new phenomena," and accommodation, when individuals' "current concepts are inadequate to allow [them] to grasp some new phenomenon successfully [so that individuals] must replace or reorganize [their] central concepts," (p.212). By applying this cognitive theory of conceptual change, teachers who are able to enhance their knowledge base undergo a transformation in their belief systems which, in turn, can alter their personal and professional perspectives.

Green (1971) writes that "when beliefs are held on the basis of evidence or reasons, they can be rationally criticized and therefore can be modified in the light of further evidence or better reasons" (p. 48). Thus a critical aspect of learning is the notion of restructuring a set of previous beliefs and attitudes that fall in line with the knowledge that is presented. Coherent and lucid explanations that accompany knowledge during the learning process are key to developing and finalizing a new set of belief structures that help enculturate the learner into accepting and believing the new knowledge.

Teacher Knowledge

With the release of *A Nation at Risk: The Imperative for Education Reform* in 1983 by the National Commission on Excellence in Education under President Ronald Reagan, the impetus towards professionalizing teaching was brought into the limelight. The primary focus of the ensuing debate on reforming the educational landscape brought forth the concept and role of teacher knowledge and its influence on classroom learning. This "missing paradigm" centered on the "study of subject-matter content and its interaction with pedagogy" (Shulman, 1999, p. ix). In his Presidential Address at the 1985 annual meeting of the American Educational Research Association, Shulman (1986) stated that the "teacher is not only a master of procedure but also of content and rationale, and capable of explaining why something is done" and that the "teacher is capable of reflection leading to self-knowledge, the metacognitive awareness that distinguishes draftsman from architect, bookkeeper from auditor" (p. 13).

The result was the concept of pedagogical content knowledge (PCK), the notion of teachers possessing a specific knowledge base (see Figures 1 and 2) that is unique to educators and is a critical component of effective teaching practices (Shulman 1987):

> The key to distinguishing the knowledge base of teaching lies at the intersection of content and pedagogy, in the capacity of a teacher to transform the content knowledge he or she possess into forms that are pedagogically powerful and yet adaptive to the variations in ability and background presented by the students (p. 13).

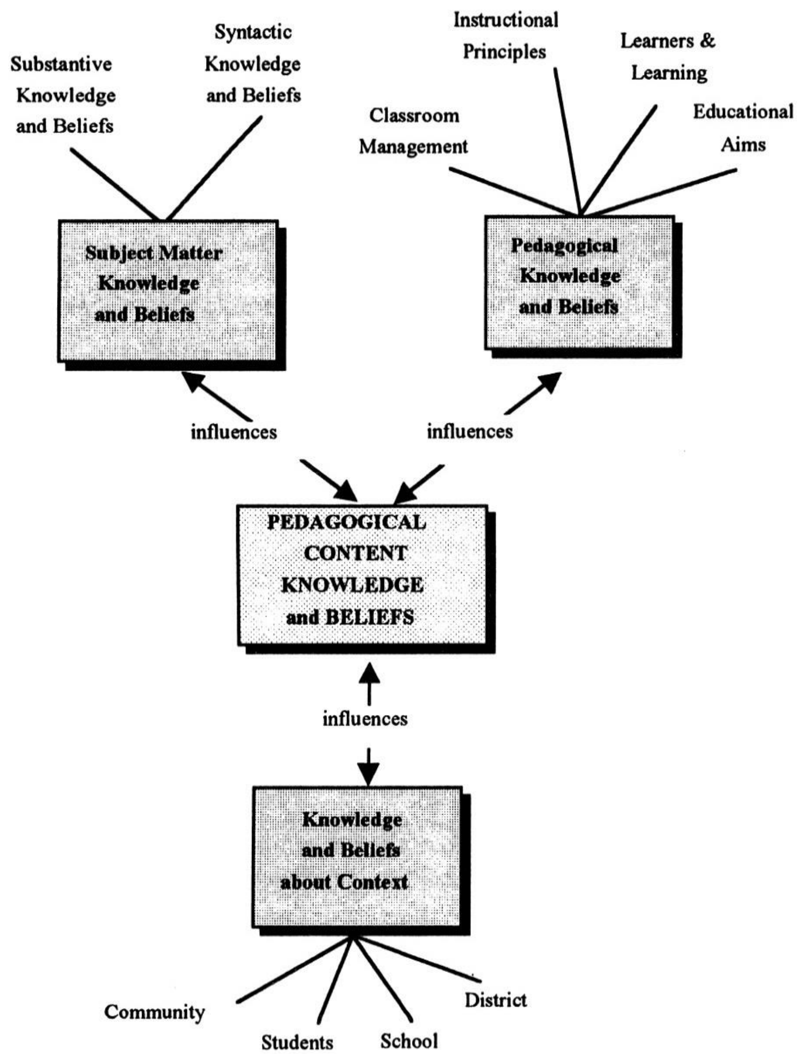


Figure 1. Domains of teacher knowledge. Reprinted from *Examining Pedagogical Content Knowledge* (p. 98) by J. Gess-Newsome and N.G. Lederman (Eds.), 1999, Dordrecht: Kluwer. Copyright 1999 by Kluwer Academic Press. Reprinted with permission.

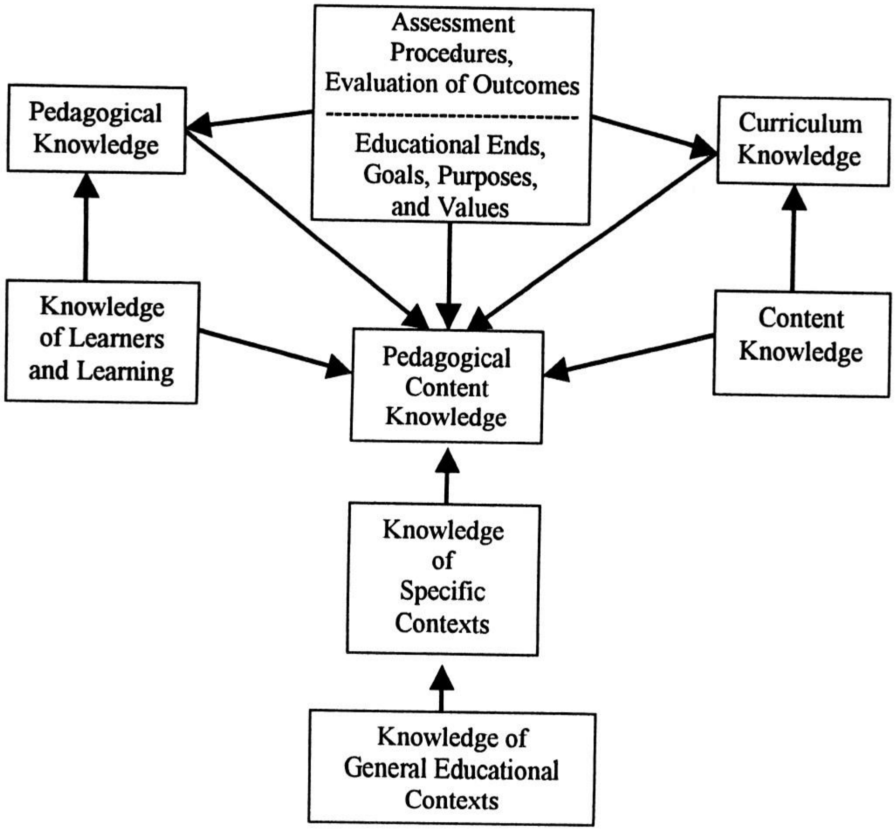


Figure 2. Categories contributing to pedagogical content knowledge. Reprinted from *Examining Pedagogical Content Knowledge* (p. 22) by J. Gess-Newsome and N.G. Lederman (Eds.), 1999, Dordrecht: Kluwer. Copyright 1999 by Kluwer Academic Press. Reprinted with permission.

Mastery of content knowledge, by itself, does not necessarily equate into individuals becoming successful teachers. The conceptual underpinning of PCK is predicated on the notion of transformation whereby the conversion of content knowledge into teachable material for students is a complex curriculum task (Deng, 2007; Magnusson et al., 1999; Wilson, Shulman, & Richert, 1987). In order to be successful, teachers must possess the knowledge to transform such content knowledge into an "understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction" (Shulman 1987, p. 8). Thus PCK has become an important new arena of research since it "embodies the aspects of content most germane to its teachability" (p. 9).

Subject Matter Knowledge

Grossman (1990) posits that the professional knowledge base of teachers consists of four components: subject matter knowledge, general pedagogical knowledge, knowledge of context, and pedagogical content knowledge. Subject matter knowledge (SMK) expertise has always been presumed to be correlated with effective teaching. With the passage of the No Child Left Behind Act (NCLB) of 2002, the United States Department of Education states that a highly qualified teacher possesses three basic requirements: teacher certification, mastery of content knowledge in a subject area, and a bachelor's degree. The assumption is that teachers who have mastered SMK would therefore be able to have the necessary tools to teach such material to students. However, findings have not been consistent. Hashweh (1987) concluded that teachers without adequate content knowledge differed in their approach in their "modifications of textbook subject matter content and their use of explanatory representations" (p. 109). Darling-Hammond (2000) postulates that in the realm of basic competence, SMK does have a positive influence but its effect wanes thereafter. Using data from the Longitudinal Survey of America, Monk (1994) demonstrates that for mathematics and science teachers, a curvilinear relationship was found between student achievement and teacher's SMK, which was measured by the number of content courses teachers took. Thus, a positive relationship was established with SMK and student achievement but as the level of SMK increased, its effect on student learning had a null effect. Moreover, Monk (1994) concludes that "pedagogy also contributes positively to student learning [with it having] more powerful effects than additional preparation in the content area" (p. 142). He states that a "good grasp of one's subject area is necessary but not a sufficient condition for effective teaching" (Monk, 1994, p. 142). Furthermore, Ferguson and Womack (1993) also found more pedagogy coursework had a better positive correlation to student achievement than SMK.

SMK, though critical in expanding the knowledge base of teachers, does not become sufficient for effective teaching. Ball and Cohen (1999) write that "teachers would need to understand the subject matter they teach, in ways different from those they learned as students" (p. 7). Facts and procedures are not sufficient, students need to learn "meanings and connections" (Ball & Cohen, 1999, p. 7). True SMK, in this sense, is what Schwab (1964) describes as content knowledge that contains both substantive and syntactical structures. Substantive structures are the "conceptual tools, models, and principles that guide inquiry in a discipline" while syntactical structures "include a discipline's canons of evidence and proof, and rules concerning how they are applied (Carlsen, 1991, p. 117). Shulman (1986) describes the need for both substantive and syntactical structures in SMK as follows:

Teachers must not only be capable of defining for students the accepted

> truths in a domain. They must also be able to explain why a particular proposition is deemed warranted, why it is worth knowing, and how it relates to other propositions, both within the discipline and without, both in theory and in practice. (p. 9)

Grossman (1990) writes that "without knowledge of the structures of a discipline, teachers may misrepresent both the content and the nature of the discipline itself" (p. 7).

Pedagogical Knowledge

General pedagogical knowledge is a facet of teacher knowledge (see Figure 3) that relates to the skills, beliefs, and general knowledge about teaching. Aspects of pedagogical knowledge include issues of classroom management/organization, general principles of instruction, and classroom communication and discourse (Grossman, 1990; Shulman & Sykes, 1986; Tamir, 1988). Furthermore, Morine-Dershimer and Kent (1999) expands on pedagogical knowledge by introducing the relationship between general pedagogical knowledge and personal pedagogical knowledge, which is derived from personal practical experience and beliefs. The link between general and personal pedagogical knowledge is the "process of reflection [which] promotes the interplay between general and personal pedagogical knowledge such that perceptions formed by personal beliefs and experiences are broadened and made more objective" (Morine-Dershimer & Kent, 1999 p. 23). The result of this relationship is a "context-specific pedagogical knowledge that helps to guide teachers' decisions and actions" (Morine-Dershimer & Kent, 1999, p. 23).

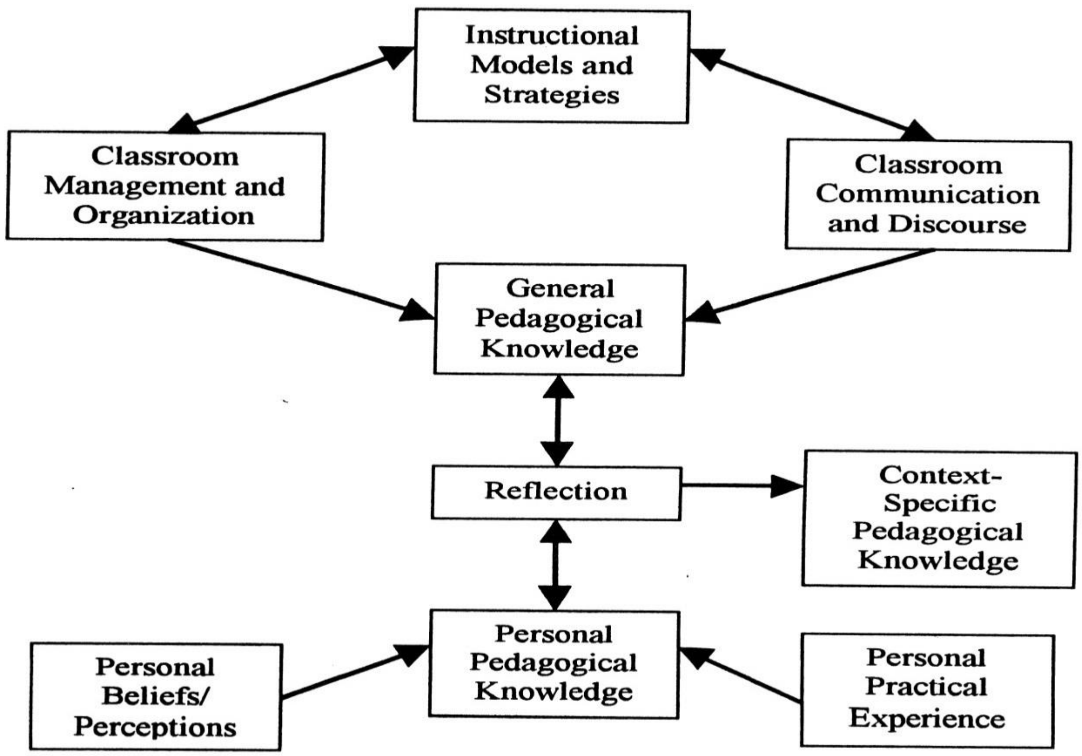


Figure 3. Facets of pedagogical knowledge. Reprinted from *Examining Pedagogical Content Knowledge* (p. 23) by J. Gess-Newsome and N.G. Lederman (Eds.), 1999, Dordrecht: Kluwer. Copyright 1999 by Kluwer Academic Press. Reprinted with permission.

Fenstermacher (1994) argues that two general types of knowledge exist for teaching: formal teacher knowledge (TK/F) and practical teacher knowledge (TK/P). TK/F is considered to be layers of objective material that needed to be merely digested by the teachers. Subject matter knowledge (SMK) can be regarded as a type of TK/F, because of its factual and unbiased content that is generally accepted to be true. TK/P, on the other hand, is "developed from participating in and reflecting on action and experience [and] is related to how to do things, the right place and time to do them, or how to see and interpret events related to one's actions" (Fenstermacher, 1994, p. 12). Clandinin (1985) defines "personal practical knowledge," a type of TK/P, as "knowledge which has risen from circumstances, actions and undergoings which themselves had affective content for the person in question [that] can be discovered in both the actions of the persons [and] by discourse or conversation" (p. 362). So TK/P is the knowledge teachers gain through their interactions in and outside the classroom, inferring that teachers have the capacity to produce knowledge through action and experience. This type of knowledge always provides the opportunity for teachers to validate and justify their belief structure, since beliefs are the "lens" from which teachers view learning (Llinares, 2002). Acquisition of the skill becomes the resultant outcome.

Knowledge of Context

Knowledge of context represents the knowledge teachers have on students and school environments:

> Knowledge of the districts in which teachers work, including the opportunities, expectations, and constraints posed by the districts; knowledge of the school setting, including the school "culture," departmental guidelines, and other contextual factors at the school level that affect instruction; and knowledge of specific students and communities, and the students' backgrounds, families, particular strengths, weaknesses, and interests. (Grossman, 1990, p. 9)

This context-specific knowledge develops as a consequence of reflecting on experiences so that as teachers "reflect on specific classroom events they are experiencing, teachers can begin to identify the particular instructional strategies, discourse patterns, and managerial techniques that best promote pupil participation and learning in that particular classroom setting" (Morine-Dershimer & Kent, 1999, p. 42).

Pedagogical Content Knowledge

Pedagogical content knowledge (PCK) is, in essence, a product of transformation from the other teacher knowledge domains. Grossman (1990) defines PCK as consisting of four critical components: (1) conceptions of purposes for teaching subject matter, (2) knowledge of students' understanding, conceptions, and misconceptions of particular topics in a subject matter, (3) curricular knowledge, and (4) knowledge of instructional strategies. In the field of science education, Magnusson et al. (1999) present a modified version of Grossman's PCK conceptual framework (see Figure 4) by adding a fifth dimension, knowledge of assessment of scientific literacy, and renaming Grossman's conceptions of purposes for teaching subject matter into orientations to teaching science.

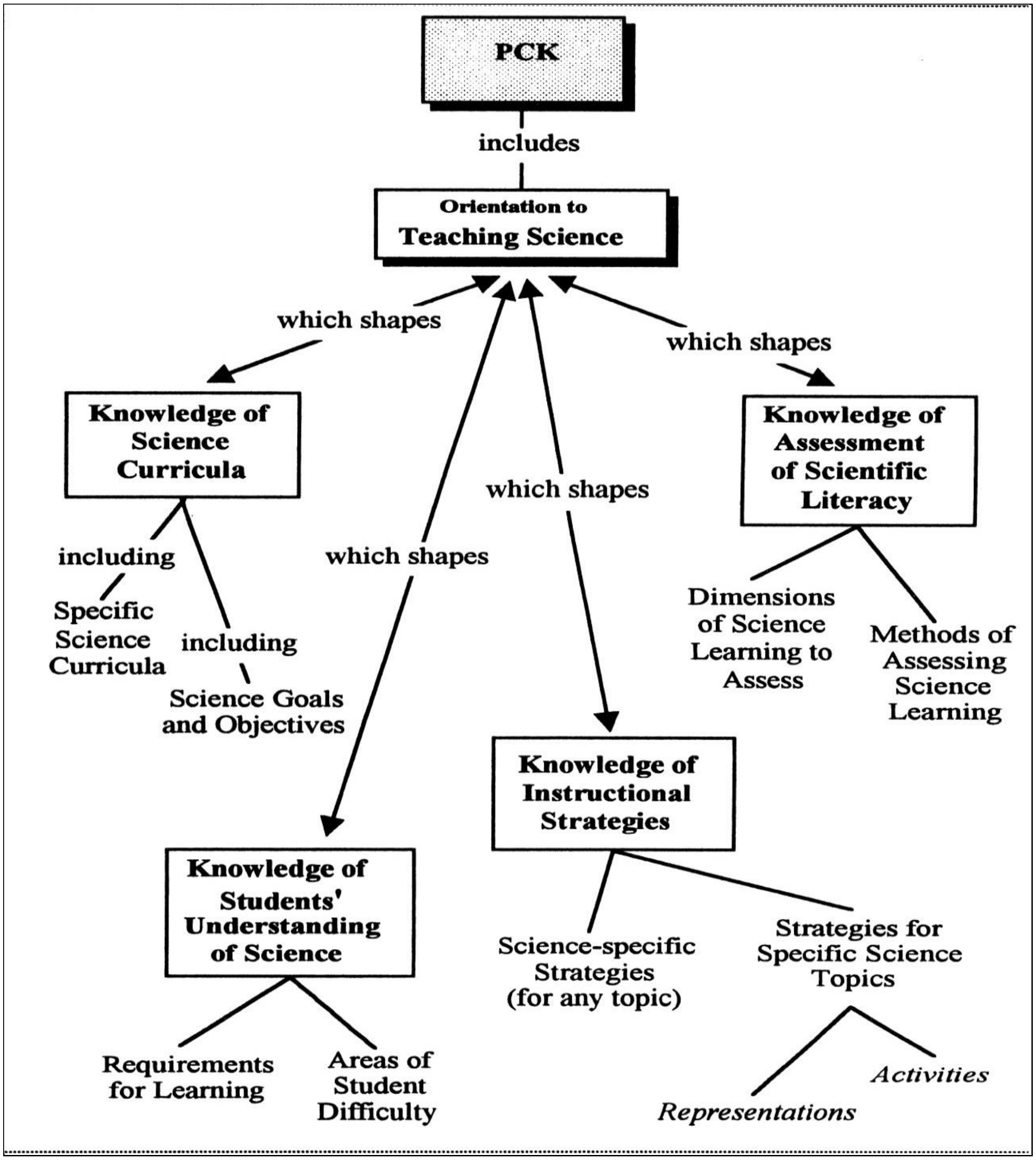


Figure 4. Model of PCK for science teaching. Reprinted from *Examining Pedagogical Content Knowledge* (p. 99) by J. Gess-Newsome and N.G. Lederman (Eds.), 1999, Dordrecht: Kluwer. Copyright 1999 by Kluwer Academic Press. Reprinted with permission.

Orientations Toward Teaching Science

The knowledge and beliefs that shapes the teacher's approach towards instructional strategies and decisions are a critical element that defines an individual's PCK. These orientations (see Figures 5 and 6) reflect the manner and method of "viewing or conceptualizing science teaching" (Magnusson et al., 1999, p. 97), thus providing teachers with a "conceptual map" to their teaching styles and methods of instruction. Nine different orientations to teaching science are listed in the Magnusson et al. (1999) science specific PCK model: (1) process, (2) academic rigor, (3) didactic, (4) conceptual change, (5) activity-driven, (6) discovery, (7) project-based science, (8) inquiry, and (9) guided inquiry.

The nine orientations to teaching science can be grouped into two categories: teacher-centered orientations and orientations that are reform and curriculum project based (Friedrichsen et al., 2011). Didactic and academic rigor represent the two teacher-centered orientations while the remaining seven orientations are sub-grouped into orientations based on the reform efforts of the 1960s (process, activity-driven, and discovery) and orientations based on contemporary reform efforts and curriculum projects (conceptual change, project-based science, inquiry, and guided inquiry).

The construct of the different science teaching orientations, which has been adapted and revised from the science teaching literature (Anderson & Smith, 1987; Grossman, 1990), is differentiated into two components: science teaching goals for teachers with a specific orientation and instructional characteristics associated with a particular orientation (Magnusson et al., 1999). Thus, for a teacher with a didactic teaching orientation, the goal of teaching science would be to "transmit the facts of science" while its accompanying instructional characteristic would be for the "teacher present(ing) information, generally through lecture or discussion, and questions directed to students are to hold them accountable for knowing the facts produced by science" (Magnusson et al., 1999, p. 100-101).

Orientation	Characteristics of Instruction
Process	Teacher introduces students to the thinking processes employed by scientists to acquire new knowledge. Students engage in activities to develop thinking process and integrated thinking skills.
Academic Rigor	Students are challenged with difficult problems and activities. Laboratory work and demonstrations are used to verify science concepts by demonstrating the relationship between particular concepts and phenomena.
Didactic	The teacher presents information, generally through lecture or discussion, and questions directed to students are to hold them accountable for knowing the facts produced by science.
Conceptual Change	Students are pressed for their views about the world and consider the adequacy of alternative explanations. The teacher facilitates discussion and debate necessary to establish valid knowledge claims.
Activity-driven	Students participate in "hands-on" activities used for verification or discovery. The chosen activities may not be conceptually coherent if teachers do not understand the purpose of particular activities and as a consequence omit or inappropriately modify critical aspects of them.
Discovery	*Student-centered*. Students explore the natural world following their own interests and discover patterns of how the world works during their explorations.
Project-based Science	*Project-centered*. Teacher and student activity centers around a "driving" question that organizes concepts and principles and drives activities within a topic of study. Through investigation, students develop a series of artifacts (products) that reflect their emerging understandings.
Inquiry	*Investigation-centered*. The teacher supports students in defining and investigating problems, drawing conclusions, and assessing the validity of knowledge from their conclusions.
Guided Inquiry	*Learning community-centered*. The teacher and students participate in defining and investigating problems, determining patterns, inventing and testing explanations, and evaluating the utility and validity of their data and the adequacy of their conclusions. The teacher scaffolds students' efforts to use the material and intellectual tools of science, toward their independent use of them.

Figure 5. Different orientations to teaching science. Reprinted from *Examining Pedagogical Content Knowledge* (p. 101) by J. Gess-Newsome and N.G. Lederman (Eds.), 1999, Dordrecht: Kluwer. Copyright 1999 by Kluwer Academic Press. Reprinted with permission.

ORIENTATION	GOAL OF TEACHING SCIENCE
Process	Help students develop the "science process skills." (e.g., SAPA)
Academic Rigor (Lantz & Kass, 1987)	Represent a particular body of knowledge (e.g., chemistry).
Didactic	Transmit the facts of science.
Conceptual Change (Roth, Anderson, & Smith, 1987)	Facilitate the development of scientific knowledge by confronting students with contexts to explain that challenge their naïve conceptions.
Activity-driven (Anderson, & Smith, 1987)	Have students be active with materials; "hands-on" experiences.
Discovery (Karplus, 1963)	Provide opportunities for students on their own to discover targeted science concepts.
Project-based Science (Ruopp et. al 1993; Marx et al., 1994)	Involve students in investigating solutions to authentic problems.
Inquiry (Tamir, 1983)	Represent science as inquiry.
Guided Inquiry (Magnusson & Palincsar, 1995)	Constitute a community of learners whose members share responsibility for understanding the physical world, particularly with respect to using the tools of science.

Figure 6. Types of instruction associated with orientations to teaching science. Reprinted from *Examining Pedagogical Content Knowledge* (p. 100) by J. Gess-Newsome and N.G. Lederman (Eds.), 1999, Dordrecht: Kluwer. Copyright 1999 by Kluwer Academic Press. Reprinted with permission.

Knowledge of Science Curriculum

The second component of PCK that is influenced by a teacher's orientation to teaching science is the knowledge teachers have of the science curriculum. This particular aspect of PCK consists of the knowledge of goals and objectives and the knowledge of specific curricular programs. The knowledge of goals and objectives includes what teachers know about the "goals and objectives for students in the subject(s) they are teaching, as well as the articulation of those guidelines across topics addressed during the school year" (Magnusson et al., 1999, p. 103). In addition, this particular knowledge base includes the vertical and horizontal curricula for a particular subject, the knowledge of "what students have studied in the past and what they are likely to study in the future" (Grossman, 1990, p. 8). The knowledge of specific curricular programs "consists of knowledge of the programs and materials that are relevant to teaching a particular domain of science and specific topics within that domain" (Magnusson et al., 1999, p. 103).

Knowledge of Students' Understanding of Science

This facet of PCK, which deals with understanding students in their development of the scientific knowledge base, consists of two parts: knowledge of requirements for learning and the knowledge of areas of student difficulty. This component thus deals with the teacher's understanding of "students' understanding, conceptions, and misconceptions of particular topics in a subject matter" (Grossman, 1990, p. 8). According to the Magnusson et al. (1999) model, the knowledge of requirements for learning "consists of teachers' knowledge and beliefs about prerequisite knowledge for learning specific scientific knowledge, as well as their understanding of variations in students' approaches to learning as they relate to the development of knowledge within specific topic areas" (p. 104).

The knowledge of areas of student difficulty relates to how teachers are able to identify and resolve learning issues confronting students in the classroom. Magnusson et al. (1999) identify three areas where students encounter difficulties when learning science: (1) science topics being too abstract and lacking any association to the students' real world experience, (2) students lacking strategies to solving problems, and (3) student misconceptions. The knowledge necessary to identify and tackle these learning difficulties constitutes the knowledge base of student difficulty that is required for the proper development of how students come to understand science. Tamir (1988) writes that knowledgeable teachers are able to design and implement instructional strategies that tackle student misconceptions as well as concepts that students find difficult to comprehend.

Knowledge of Assessment in Science

This component of PCK encompasses two elements: knowledge of the dimensions of science learning to assess and the knowledge of the methods of assessment. For the first, knowledge of dimensions of science learning to assess, Magnusson et al. (1999) define it as being based on scientific literacy so that "teachers be knowledgeable about some conceptualization of scientific literacy to inform their decision-making relative to classroom assessment of science learning for specific topics" (p. 108). Knowledgeable teachers will, thus, be able to pinpoint what dimensions of scientific literacy are to be assessed on a particular topic or subject matter.

The knowledge of methods of assessment is a category that entails the use of assessment to gauge student learning. In science education, teachers have a variety of assessments that can evaluate student learning, such as the use of written examinations, laboratory tests and notebooks, and it is this knowledge and how it is used that makes up this particular knowledge base, which "includes knowledge of specific instruments or procedures, approaches or activities that can be used during a particular unit of study to assess important dimensions of science learning as well as the advantages and disadvantages associated with employing a particular assessment device or technique" (Magnusson et al., 1999, p. 109). Tamir (1988) writes that such testing and evaluation requires the teacher to possess specific pedagogical knowledge "certain principles and methods of student assessment [while it] cut across subject matter areas, others are unique to particular disciples [like] the design, administration, and assessment of practical laboratory tests in science education" (p. 106).

Knowledge of Instructional Strategies

This last component of PCK has two parts: knowledge of subject-specific strategies and knowledge of topic-specific strategies. Instructional strategies are a pertinent facet of teaching since the varied activities and representations presented by the teacher enhances the learning environment for students. The knowledge of subject-specific strategies, which includes "general approaches to or overall strategies for enacting science education, is related to the 'orientations to teaching science' component of pedagogical content knowledge in that there are general approaches to science instruction that are consistent with the goals of particular orientations" (Magnusson et al., 1999, p. 110). Citing research that implicates teachers whose content and pedagogical knowledge were lacking led to an ineffective use of subject-specific strategies (Marek, Eubanks & Gallaher, 1990; Smith & Neale, 1989), Magnusson et al. (1999) surmise that PCK development "relative to [the knowledge of subject-specific strategies] requires drawing upon the three base domains of teacher knowledge: subject matter, pedagogy, and context" (p. 111).

The knowledge of topic-specific strategies, which covers instructional strategies on specific concepts in science, has two categories: topic-specific representations and topic-specific activities. For topic-specific representations, Magnusson et al. (1999) define it as the knowledge base that "represent specific concepts or principles in order to facilitate student learning, as well as knowledge of the relative strengths and weaknesses of particular representations, [in addition it includes] a teacher's ability to invent representations to aid students in developing understanding of specific concepts or relationships" (p. 111). Examples of topic-specific representations in science might include the use of analogies, models, illustrations, and examples to help students understand the underlying concepts in science.

Topic-specific activities, on the other hand, are activities such as experiments, simulations, and demonstrations to aid students better comprehend scientific relationships and concepts. Furthermore, this knowledge base “also includes teachers’ knowledge of the conceptual power of a particular activity; that is, the extent to which an activity presents, signals, or clarifies important information about a specific concept or relationship” (Magnusson et al., 1999, p. 113).

Development of Pedagogical Content Knowledge

PCK is a dynamic, rather than static, category (Abell, 2008) of teacher knowledge that gets molded through experience and beliefs. Grossman (1990) postulates that PCK develops through four distinct avenues: (1) apprenticeship of observation, (2) disciplinary background, (3) professional coursework, and (4) learning from experience.

The “apprenticeship of observation” (Lortie, 1975) is an intrinsic process that lures prospective teachers to reflect on their own experiences as students to grasp the underpinnings of teaching. The successes and challenges experienced during their time spent being a student allows prospective teachers to use such perspectives as a guide to becoming teachers. Such an apprenticeship of observation presents a sometimes narrow view of teaching and learning, making it difficult for teachers to realize alternative ideas of teaching because it has been reinforced through many years spent being a student (Grossman, 1990; Feiman-Nemser, 1983; Feiman-Nemser & Buchmann, 1985; Lortie, 1975). Furthermore, this construed understanding of teaching experienced by students tends to be “intuitive and imitative rather than explicit and analytical [since] it is based on individual personalities rather than pedagogical principles” (Lortie, 1975, p. 62).

Nevertheless, the resulting outcome of such experiences and memories provide a rudimentary framework for PCK to develop in novice teachers. Grossman (1990) posits that the instructional strategies, knowledge of student understanding, and curricular knowledge beginning teachers were exposed to as students contributes to their initial PCK. "Experiences as students provide prospective teachers with memories of strategies for teaching specific content, to help shape their own expectations of students, [and to use] particular texts and topics [because they are] likely to remember aspects of the curriculum" (p. 10-11).

A second source of PCK deals with the disciplinary background of the teachers themselves. Thus a teacher's comprehension and background of subject matter would "affect their conceptions of what it means to teach a particular subject [and to the] selection of particular curricula and to their critiques of specific curriculum materials" (Grossman, 1990, p. 12). In this regard, curricular knowledge as well as the conceptions (teaching orientations) of teaching can be attributed to the teacher's disciplinary background and knowledge of content.

Professional coursework in education as well as professional development programs that cater towards developing strategies of methods is another arena where PCK can cultivate. Exposing teachers, new and experienced, to a variety of instructional strategies and approaches to learning would assist in enhancing their understanding of the professional knowledge base. Research suggests that effective coursework and professional development programs can improve the teacher's understanding of student misconceptions on particular concepts (Smith & Neale, 1989) as well as enhancing the teacher's representational and adaptational repertoires (Clermont, Krajcik, & Borko, 1993).

Classroom experience constitutes another avenue for PCK to develop. Teachers, as they become acclimated to the classroom environment, begin to realize and acknowledge student conceptions and misconceptions and therefore suite their instructional strategies to match the learning needs of the student. Teaching experience, thus, becomes a critical and major source of PCK.

Model and Conceptualization of Pedagogical Content Knowledge

Shulman (1986) argues PCK as incorporating "ways of representing and formulating the subject that make it comprehensible to others" (p. 9). The inclusion of PCK as part of the teacher knowledge base thus brought into the limelight the importance of teacher knowledge and learning and its critical role of developing effective teachers. Ever since Shulman (1986, 1987) introduced the genre of PCK into the education milieu over twenty five years ago, insight into the manifestations and development of PCK has been examined to delineate the dynamic nature of the PCK construct.

Various models of PCK, based on Shulman's original synthesis (Banks, Leach, & Moon, 2005; Cochran et al., 1993; Fernández-Balboa & Stiehl, 1995; Grossman, 1990; Koballa, Gräber, Coleman, & Kemp, 1999; Magnusson et al., 1999; Marks, 1990; Veal & MaKinster, 1998), provide further insight into the complexity and multifaceted characteristics inherent in the professional knowledge base of teachers. Although the academic construct and interpretation of PCK may differ from one research group to the next, the common thread that is present is the concept of knowledge acquisition and how vital this is in nurturing the development of PCK in teachers.

The Grossman (1990) and Magnusson et al. (1999) models, which are closely aligned with Shulman's formulation of PCK, are grounded on the premise of a "teacher's understanding of how to help students understand specific subject matter" (Magnusson et al., 1999, p. 96). As a result, both models place content knowledge as a distinct and separate category of teacher knowledge thereby defining PCK as the knowledge teachers use to transform subject matter that is appropriate for students. On the other hand, models have been proposed that argue that content knowledge is an inherent part of PCK rather than being independent of one another (Fernández-Balboa & Stiehl, 1995; Koballa et al., 1999; Marks, 1990) since content knowledge and PCK are seen as being indistinguishable from one another.

The key distinction between the two PCK models, whether or not content knowledge is an integral part of PCK, forms the basis of the difference between an integrative and transformative model of teacher knowledge (Gess-Newsome, 1999). In the integrative model, teacher knowledge is composed of subject matter, pedagogy, and context and that PCK, by itself, does not exist. The knowledge that teachers use in the classroom is therefore an integration of the three knowledge constructs and it is this that defines the teachers PCK so that "PCK is the knowledge that teachers have and use in the classroom, of which SMK is an integral part" (Kind, 2009, p. 180). On the other hand, the foundation of the transformative model is grounded on the concept of transforming existing knowledge into forms that are comprehensible to students, thereby creating the

PCK knowledge set that is the "synthesis of all knowledge needed in order to be an effective teacher" (Gess-Newsome, 1999, p. 10), enabling teachers to develop PCK using their existing content knowledge.

The foundation of PCK rests on the development and eventual transformation of the teacher knowledge base. Therefore, the interrelationship among content knowledge, pedagogical knowledge, and the knowledge of context plays a vital role in shaping an individual teacher's PCK. In doing so, PCK becomes a highly individualistic and dynamic component of the knowledge base. This is the result of the influences the major teacher knowledge domains have on each other and on the development of PCK. Magnusson et al. (1999) provide two examples (see Figure 7) of the underlying influences of the teacher knowledge base (SMK, pedagogical knowledge, and knowledge of context) have on PCK development. In the scenario, two hypothetical teachers are presented, one whose knowledge of subject matter is greater than the other while the second teacher possesses a greater understanding of pedagogy. This circumstance "may mean that if these teachers taught the same topics in the same educational context they would develop different PCK" (p. 118). Therefore the distinctive characteristics of how PCK develops are grounded on not only the level of knowledge comprehension but also on the level of value the teacher places on each of the knowledge domains.

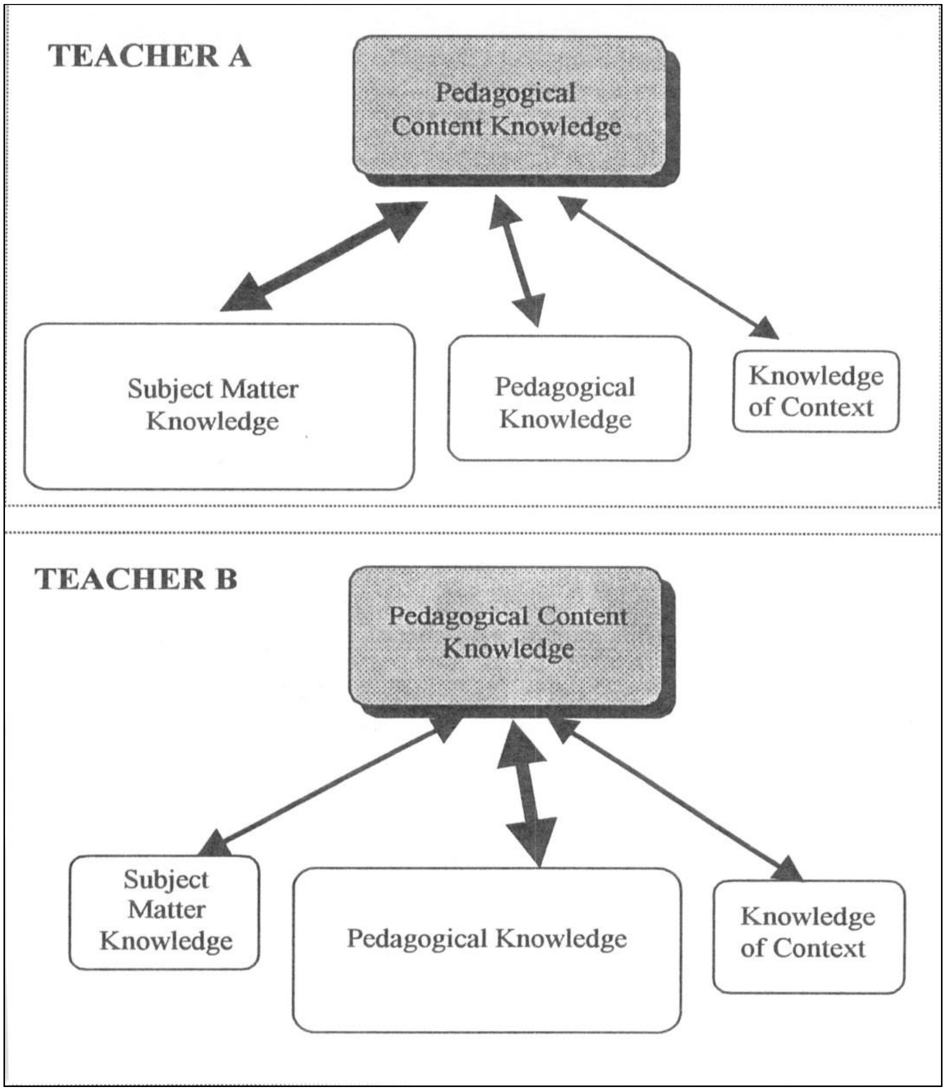


Figure 7. Influences of the development of pedagogical content knowledge. Reprinted from *Examining Pedagogical Content Knowledge* (p. 119) by J. Gess-Newsome and N.G. Lederman (Eds.), 1999, Dordrecht: Kluwer. Copyright 1999 by Kluwer Academic Press. Reprinted with permission.

Due to the inherent variability of content knowledge and pedagogy among teachers, the grounding and development of PCK becomes highly customized.

Furthermore, PCK becomes an extremely dynamic domain of teacher knowledge as teachers augment their knowledge base through their practice in the classroom. The foundation for this personalization of the teacher knowledge base takes root from the teachers' own personal beliefs and experiences that form the basis of their personal pedagogical knowledge (Morine-Dershimer & Kent, 1999). This personal pedagogical knowledge, or what Clandinin (1985) called personal practical knowledge, gets molded from the circumstances and actions undertaken by the teacher. The conduit that links the teacher's personal pedagogical knowledge to their general pedagogical knowledge is the reflection process that "promotes the interplay between general and personal pedagogical knowledge such that perceptions formed by personal beliefs and experiences are broadened and made more objective" (Morine-Dershimer & Kent, 1999, p. 22-23). The nomenclature that results from such a reflection process is what Morine-Dershimer & Kent (1999) call context-specific pedagogical knowledge since the interplay between action and reflection relates to specific situations and environments.

Because overall pedagogical knowledge is a fundamental construct of PCK, the constructivist role of developing PCK becomes a critical player in shaping the teachers knowledge base. Cockran et al. (1993) posit that this active process increases the awareness of teachers have on the needs of their students and how such results plays an essential role in the development of the teachers' PCK. This also supports the supposition of how experience plays a vital role in PCK development (Grossman, 1989, 1990; Peterson, Fennema, Carpenter, & Loef, 1989) since the knowledge base is "modified and influenced by practice" (Turner-Bisset, 1999, p. 42).

Research Basis of PCK

"The ultimate test of understanding rests on the ability to transform one's knowledge into teaching" (Shulman, 1986, p. 14). This statement illuminates just how significant PCK is to improving the classroom learning environment, but, at the same time, demonstrates the abstract concept of PCK by attempting to link the idea of scholarship to practice (Berry, Loughran, & van Driel, 2008). The knowledge base of teachers is a dynamic and evolving asset that, ultimately, shapes and personalizes PCK for each teacher. To better understand the generative nature of teacher knowledge, particularly PCK, a constructivist view of learning must be appreciated in how it serves as a lens to the development of teacher knowledge. The teacher knowledge base is an active process that constantly readjusts itself to changing circumstances (Cochran et al., 1993). Since PCK is rooted in the teacher's knowledge of subject matter, pedagogy, and context, further articulation of the domains of teacher knowledge becomes important in better understanding the mechanism of action of PCK.

The domains of teacher knowledge, especially content knowledge and pedagogy, serve as the foundation from which PCK takes root. First, content knowledge is an essential element for PCK to develop and serves as a necessary prerequisite (Hashweh, 1987; Grossman, 1990; Lederman et al., 1994; Özden, 2008; van Driel et al., 1998). Having sufficient knowledge of the subject matter allows the teacher to better understand misconceptions students might have during instruction since a lack of content knowledge will hinder the transformative process that is the hallmark of PCK (Halim & Meerah, 2002). Furthermore, teachers with strong content knowledge have been shown to factor in the needs of the students by considering instructional strategies that can be tailored to the students (van Driel et al., 2002). In their study of pre-service teachers, Sperandeo-Mineo, Fazio and Tarantino (2006) conclude that teachers who lack sufficient content knowledge tend to possess similar misrepresentations as their students thereby producing an inadequate base of PCK. Having sufficient understanding of the subject matter allows the teacher not only to explore new instructional strategies but to be able to detect and correct misconceptions that students might hold on a particular topic (Warren & Ogonowski, 1998).

Furthermore, the cognitive component of the knowledge base, which includes important aspects of pedagogical knowledge, plays a vital part in the development of effective PCK. This dimension includes the beliefs and attitudes teachers hold as well as the role of classroom experience has in shaping the belief structure. This "knowing in action" mechanism (Cochran et al., 1993) becomes critical in shaping the beliefs of teachers through the active process of reflection. As a result, classroom experience becomes the key factor in helping to shape and mold PCK (Grossman, 1990; Toh & Tsoi, 2008). As the act of teaching raises awareness of the needs of students and as exposure in the classroom increases, the belief structure acclimates to better grasp the learning environment that ultimately helps in developing PCK (Veal, 1999). This supports the assumption that the act of teaching has a crucial role in modifying and changing the knowledge base (Lederman et al., 1994). Moreover, Henze et al. (2008) write that "teachers' PCK development seems to be related to their initial pedagogical perspectives, epistemological views, and subject matter knowledge" (p. 1340).

The influence of pedagogical knowledge in shaping PCK also determines the type of instruction carried out by the teacher. In the Magnusson et al. (1999) model of PCK, the orientations to teaching science is a major component of PCK that, in turn, influences the other four components. As a result, the type of teaching orientation as teacher has dictates how PCK gets embedded in their practice. Friedrichsen et al. (2009) conclude that teaching orientations "filtered [the teacher's] instructional decision-making" and that such orientations are "strongly held and may be difficult to change" (p. 376). Therefore, the role of reflection, via effective mentoring and collaboration, can help alter the belief landscape to modify the teacher's instructional approach (van Driel et al., 2002). In addition, in their study of pre-service chemistry teachers, researchers were able to determine that changes in PCK development were noted when prospective teachers were willing to reflect and undergo the necessary changes as their perceptions of teaching evolved (Tuan, Jeng, Whang, & Kaou, 1995). It is through such a process of actively reflecting on the value and belief structure of the teacher's personal pedagogical knowledge that contributes to its malleability.

Research has produced several key characteristics of PCK that are relevant for its development and sustainability. First, content knowledge is critical and is seen as a necessary prerequisite for PCK development since it lays down the foundation of the knowledge base (Abell, 2008; Kind, 2009). Secondly, classroom experience is seen as a vital component that shapes PCK since "perceptions of science alter [as teachers gain experience that results in] moving from thinking of science as a subject that they learned at a high level, to realizing how the subject is interpreted for school contexts" (Kind, 2009, p. 186). These features advance the notion of PCK being a dynamic facet of the knowledge base that can be customized and tailored to specific learning styles and circumstances through cognitive and learning changes that occur.

Teacher Empowerment

The construct of teacher empowerment is another arena of teacher education research that warrants closer examination in its role in developing effective teachers. Empowerment, defined as a "process whereby school participants develop the competence to take charge of their own growth and resolve their own problems," is a critical element that plays a significant role in shaping the teacher knowledge base since "empowered individuals believe they have the skills and knowledge to act on a situation and improve it" (Short, 1994, p. 488).

> Teacher empowerment requires teachers to commit to the task of continuous experimentation, investigation, inquiry, and study, to negotiating the troubled waters of teaching, to growing and learning for an entire lifetime in the classroom. It requires that teachers create a space for problem posing and problem solving, historical and theoretical considerations, storytelling, and critical reflection. (Ayers, 2010, p. 861)

The systemic role of empowerment in solidifying and elevating the professionalism of teachers through both extrinsic and intrinsic factors of the educational environment (Hobbs, 2004; Moreland, 2011) is a pertinent avenue for developing effective teachers. This broad reach of how empowerment can promote teachers into becoming more sanguine about their teaching abilities becomes vital in reinforcing the principles and beliefs necessary to attain teaching mastery. The praxis of sound teaching strategies is modeled from teachers becoming better cognizant of their abilities and being afforded the necessary support system to be successful in the classroom. Empowerment, therefore, becomes a critical component for teacher education and development, which explains why attrition rates for empowered teachers are inclined to be lower as a result of increased job satisfaction and performance (Hobbs, 2004; Moreland, 2011).

Teacher empowerment is a multifaceted paradigm consisting of six dimensions (Short, 1994): decision making, professional growth, status, autonomy, impact, and self-efficacy. Because the empowerment theme is manifold, the self-efficacy dimension will be the focal point of the discussion since its relationship with the acquisition and retention of the teacher knowledge base is most germane. Nevertheless, the other facets of the empowerment theme will be briefly discussed to provide the reach of empowerment in teacher development.

Decision Making

Short argues that teacher decision making "means participation in and responsibility for decisions involving budgets, teacher selection, scheduling, curriculum, and other programmatic areas" (Short, 1994, p. 489). Providing teachers with the opportunity to have ownership of their activities in and out of the classroom is an important parameter in teacher empowerment since it enables teachers to have a greater sense of responsibility for how student learning takes place in the classroom. Thus, as Short writes, "as teachers feel more empowered, they recognize that they have the power to identify problems, institute change efforts, and ultimately, to take responsibility for solving the problem" (Short, 1994, p. 489).

Professional Growth

The second dimension of teacher empowerment is the concept of professional growth. Teachers are able to grow professionally through a variety of avenues that helps them develop better skills to better equip themselves in the classroom, such as attaining a better command of teacher knowledge or teaching strategies. Short (1994) defines the empowerment of professional growth as the "teachers' perceptions that the school in which they work provides them with opportunities to grow and develop professionally, to learn continuously, and to expand one's own skills through the work life of the school" (p. 490).

Status

The status dimension of teacher empowerment "refers to teacher perceptions that they have professional respect and admiration from colleagues [and] that they have colleague support [as well as feeling] that others respect their knowledge and expertise" (Short, 1994, p. 490). Therefore, providing teachers with the proper infrastructure and support needed to help them better navigate both the classroom and school environments will garner the respect and status necessary to feel more empowered in their work. Moreland (2011) argues that such professional respect can also be "earned from the knowledge and expertise that teachers professionally demonstrate to their peers and ideally results in colleagues and administrators supporting the teachers' actions" (p. 32).

Autonomy

Defined by Short (1994) as referring to "teachers' beliefs that they can control certain aspects of their work life [such as] scheduling, curriculum, textbooks, and instructional planning" (p. 490-491), autonomy provides the teacher with the freedom necessary to make decisions relevant in the classroom. This independence, which can be closely aligned with the decision making dimension of empowerment, facilitates teachers into believing in themselves that they possess the ability to steer and change situational conditions that better fit their needs as teachers.

Impact

The impact dimension of teacher empowerment "refers to teachers' perceptions that they have an effect and influence on school life" (Short, 1994, p. 491). Being recognized for accomplishments and lauded for work done in the classroom has a tremendous influence on a teacher's self-esteem which, in turn, can sway student learning in a positive manner. Therefore, the impact category of teacher empowerment is pertinent in raising motivation levels of teachers. Short writes that "teachers require challenges and support in order to grow personally and professionally" (Short, 1994, p. 491).

Self- Efficacy

The sixth dimension of Short's (1994) teacher empowerment dimension is the element of self-efficacy. Described by Short as "teachers' perceptions that they have the skills and ability to help students learn, are competent in building effective programs for students, and can effect changes in student learning," self-efficacy cultivates as "individuals acquires self-knowledge and the belief that they are personally competent and have mastered skills necessary to effect desired outcomes" (p. 490). Since its emergence in the research literature in the mid-1970s, the role of efficacy has evolved to capture and value the cognitive aspects of teacher effectiveness (Armor et al., 1976; Berman & McLaughlin, 1977; Brophy & Evertson, 1977; Guskey, 1988). Teachers' "sense of efficacy in teaching and learning situations [is] a powerful variable in studies of instructional effectiveness" (Guskey & Passaro, p. 628, 1994) since their beliefs in their abilities to affect student learning enables them to "set higher expectations, exert greater effort and persist in the face of difficulties" (Ngidi, p. 140, 2012).

Teacher Efficacy

Teacher efficacy is defined as the "teachers' belief or conviction that they can influence how well students learn, even those who may be considered difficult or unmotivated," (Guskey & Passaro, 1994, p. 628) has become an emerging arena for the research of teacher development (Gibson & Dembo, 1984; Ngidi, 2012; Tschannen-Moran, Woolfolk Hoy, & Hoy, 1998; Woolfolk Hoy, Hoy, & Kurz., 2008). Research has shown a distinct relationship between student achievement and the efficacy levels of teachers (Armor et al., 1976; Ashton & Webb, 1986; Gibson & Dembo, 1984). Furthermore, efficacious teachers tend to possess a higher set of expectations as well as having a greater personal responsibility for student learning (Brophy & Evertson, 1977).

Teacher efficacy was first brought into the educational research genre by Armor et al. (1976) utilizing the conceptual underpinnings of Rotter's social learning theory (1966), which is predicated on the concept of "whether control of reinforcement lay within themselves or in the environment" (Tschannen-Moran et al., 1998, p. 202). The internal versus external control of reinforcement of Rotter's (1966) theoretical framework theorizes that teachers who have confidence in their teaching ability to motivate student learning possess the belief that the reinforcement of their teaching skills is within their control [internal] whereas teachers "who concur that the influence of the environment overwhelms a teacher's ability to have an impact on a student's learning exhibit a belief that reinforcement of their teaching efforts lies outside their control, or is external to them" (Tschannen-Moran et al., 1998, p. 204).

Another theoretical framework contributing to the construct of teacher efficacy is based on the work of Bandura's (1977) social cognitive theory on self-efficacy. He writes that "cognitive processes mediate change but that cognitive events are induced and altered most readily by experience of mastery arising from effective performance" (p. 191). By employing a cognitive lens, Bandura (1977, 1982, 1993) postulates that self-efficacy, which he defines as an individual's belief of "how well one can execute courses of action required to deal with prospective situations" (1982, p. 122), can be viewed as a vehicle for behavioral change. Thus self-efficacy is a "future-oriented belief about the level of competence a person expects he or she will display in a given situation" (Tschannen-Moran et al., 1998, p. 207-208). Moreover, levels of perceived self-efficacy will invariably adjust itself depending on psychological changes that affect the individual. Bandura writes that "expectations of personal efficacy determine whether coping behavior will be initiated, how much effort will be expended, and how long it will be sustained in the face of obstacles and aversive experiences" (1977, p. 191).

The mechanism of Bandura's social cognitive theory involves two modes of operation: efficacy expectations and outcome expectations:

> An outcome expectancy is defined as a person's estimate that a given behavior will lead to certain outcomes. An efficacy expectation is the conviction that one can successfully execute the behavior required to produce the outcomes. Outcome and efficacy expectations are differentiated, because individuals can believe that a particular course of action will produce certain outcomes, but if they entertain serious doubts about whether they can perform the necessary activities such information does not influence their behavior. (p. 193)

The premise of self-efficacy theory, therefore, lies in the notion of "self-perception of competence rather than actual level of competence" since it is situated in "beliefs about whether one can produce certain actions" (Tschannen-Moran et al., 1998, p. 211). Furthermore, Ashton and Webb (1986) refer to such perceptions of ability as a personal efficacy trait of teachers (self-efficacy) while outcome expectancy is argued to be teaching efficacy because it involves the abilities of teachers relevant to student motivation and performance.

The cognitive feature of efficacy expectations originates from four distinct sources: (1) performance accomplishments, (2) vicarious experience, (3) verbal persuasion, and (4) emotional arousal (Bandura, 1977). Performance accomplishments refer to an individual's mastery of actions so that "successes raise mastery expectations; repeated failures lower them [so that] after strong efficacy expectations are developed through repeated success, the negative impact of occasional failures is likely to be reduced" (Bandura, 1977, p. 195). Vicarious experience is the concept of modeling after others so that "seeing others perform can generate expectations (for the individual) that they too will improve if they intensify and persist in their efforts" (Bandura, 1977, p. 197). Third, verbal persuasion is denotes how individuals can raise their self-efficacy expectations through "suggestion into believing they can cope successfully with what has overwhelmed them in the past" (Bandura, 1977, p. 198). Lastly, efficacy expectations can be raised through a state of emotional arousal, such as excitement or anxiety, since "stressful and taxing situations generally elicit emotional arousal that might have informative value concerning personal competency" (Bandura, 1977, p. 198).

By unifying both Rotter's (1966) internal-external locus of control theory with Bandura's (1977) social cognitive theory of self-efficacy, researchers have come to quantify teacher efficacy and its effect on student learning (Armor et al., 1976; Ashton & Webb, 1986; Gibson & Dembo, 1984; Guskey, 1981; Riggs & Enochs, 1990). Starting with a study done by the RAND (Research and Development) corporation (Armor et al., 1976), which incorporated Rotter's social learning theory, to the development of the Gibson and Dembo (1984) teacher efficacy instrument that incorporated both Rotter's and Bandura's theories on efficacy, instruments that were able to measure teacher efficacy brought into light how "teachers' classroom behaviors, their openness to new ideas, and their attitudes toward teaching [can] influence student achievement, attitude, and affective growth" (Tschannen-Moran et al., 1998, p. 215). Furthermore, the evolution of instruments available enabled researchers to home in on various subject matter topics since teacher efficacy has been "defined as both context and subject-matter specific" (Tschannen-Moran et al., 1998, p. 215).

CHAPTER 3: METHODOLOGY

Methodological Overview

The principal basis for this study was to qualitatively examine the developmental underpinnings of PCK through the cognitive lens of teacher efficacy. Qualitative techniques were chosen because such methods offer a much more detailed and lucid portrait of the learning environment. The central premise of an epistemological study is based on observing and describing the setting or context that leads to professional growth. Miles and Huberman (1994) write that qualitative data are a "source of well grounded, rich descriptions and explanations of processes in identifiable local contexts" which can then be used to "preserve chronological flow, see precisely which events led to which consequences, and derive fruitful explanation" (p. 1). As a result, the best avenue to illustrate and define the conditions that play a role in empowering teachers to develop their PCK will be through an in-depth case study analysis.

Since case studies can describe the circumstances and conditions that may influence the growth of teachers, the decision to perform a case study became necessary. Yin (2003) writes that case studies are "the preferred strategy when 'how' or 'why' questions are being posed, when the investigator has little control over events, and when the focus is on a contemporary phenomenon within some real-life context" (p.1). Thus, in order to better understand how experienced teachers develop and sustain their PCK and why teacher efficacy effects PCK growth, a case study was performed with a varied group of experienced science teachers.

The conceptual framework underlying the foundation of this study was based on a social-constructivist model (Driver et al., 1994), which accepts the "view that scientific knowledge is socially constructed, validated and communicated" (p. 11). In addition, an integral component of the framework features Bandura's (1977) social cognitive theory which "posits that people are motivated to perform an action if they believe the action will have a favorable result (outcome expectation), and they are confident that they can perform that action successfully (self-efficacy expectation)" (Bleicher, 2004, p. 384). And since "scientific knowledge is discursive in nature" (Driver et al., p. 11), social interactions and the subsequent changes that occur in the teacher's belief system structure become the focal point in knowledge construction.

A social-constructivist "perspective recognizes that learning involves being introduced to a symbolic world" since "knowledge and scientific understandings are constructed when individuals engage socially in talk and activity about shared problems or tasks" (Driver et al., p. 7). And by coupling this framework with the sociological and cognitive paradigm of teacher efficacy will allow a fuller and more balanced understanding of teacher development. This rationale punctuates the distinctive and critical role played by both cognitive events and processes in shaping the teacher's capacity for learning and growth. Grounding the study on a social-constructivist framework that incorporates Bandura's (1977) theory of social learning will therefore help situate the approach of conceptual changes that occur during classroom activities since "social structures are created by efficacious human activity" (Bleicher, 2004, p. 384).

Research Questions

The principal basis for this case study was to comprehend the developmental growth of PCK and how teacher efficacy plays a role in sustaining PCK growth among experienced science teachers. Thus the primary research questions that were addressed from this study are the following:

1. Does PCK evolve over time among experienced science teachers? If so, how? And how does classroom experience contribute to PCK development?
2. Does teacher efficacy among science teachers enhance the development of PCK? If so, how?

Design and Instrumentation

This qualitative study involved a case study of three experienced science teachers, with at least eight years of teaching experience, as they teach a specific unit of study. Since a "case study method allows investigators to retain the holistic and meaningful characteristics of real-life events" (Yin, 2003, p. 2), qualitative methods became necessary in order to describe the circumstances that surround knowledge development in their "natural settings" (Denzin & Lincoln, 2000, p. 3). So through this case study approach, a systematic account of the phenomena of teacher growth was explored to better comprehend the circumstances and surroundings that are attributed to the growth of PCK. Because such measures provide a richer more descriptive portrait of the classroom, a case study approach affords the opportunity to witness and capture the critical events that are responsible for teacher learning.

The inherent design of the case study that was performed was based on the learning interactions that occur in the classroom between teacher and student. The nature of such social interactions was examined through the use of classroom observations and semi-structured interviews to illustrate and pinpoint the developmental stages responsible for effective learning. The study also examined the role of teacher efficacy and how it influenced professional growth in experienced teachers, especially to its relationship to teacher knowledge. Thus the exploratory basis for PCK development in experienced science teachers, as it relates to classroom experience under the guise of teacher efficacy, was studied to better understand the complexities of knowledge growth.

The overall design of the case study revolved around observing and probing an experienced science teacher's continued professional development in order to ascertain and comprehend the influences that contribute to that growth. Furthermore, the study focused on observing the actions and interactions of the teacher, *in vivo*, in the classroom environment to help provide the opportunity to learn more about the continuing growth of PCK. Narrowing the parameters of the study to experienced science teachers, who already possess varying high degrees of PCK, aided in illuminating the factors responsible for a veteran science teacher's continuing development of their PCK. To this end, two established case study instruments were utilized to obtain data: classroom observations and semi-structured interviews.

Classroom Observations

First, observations were performed in the participating teachers' classrooms to better understand the social interactions that took place during a lesson. Artifacts collected (lesson handouts, unit exams, and quizzes) during this phase of the study determined the current state of the knowledge base, particularly that of PCK, of the teachers and how the teachers implemented their lessons. Observational protocols that relate to the explanation and feedback of the lesson as well as student responses and their corresponding synthesis to the lesson were used to determine the capacity and capability of each teacher. Observations were conducted for two units of lesson study, which lasted from two to three weeks each, to first isolate episodes of PCK and frequency of use during a lesson, as well as how teachers are able to overcome obstacles that confront them if their level of comprehension becomes insufficient.

Teachers were observed, through their actions and use of discourse, to realize the influence of social interactions in their approach to lesson planning and teaching. By observing the social interactions that take place between the teacher and his/her students, student actions and responses became a key observational tool. This was the result of the actions taken by teachers in response to student output and questioning.

PCK Instrumentation

Embedded within the classroom observational protocol was the PCK instrument that was used during classroom observations. Because of the dynamic and specialized nature of PCK, there has not been a tested instrument in educational research literature that can be universally applied. Baxter and Lederman (1999) write that "assessments of pedagogical content knowledge need to highlight a teacher's ability to deal with the unusual, non-generalizable aspects of teaching" (p. 151). In addition, they state that the "relationship between cognition and action is highly complex and certainly not automatic" (Baxter and Lederman, 1999, p. 159) which led to the decision to qualitatively capture and portray PCK in action.

This instrument for observing PCK was designed and studied by Loughran et al. (2004, 2006) who formulated a framework that can be used to capture a science teacher's PCK:

> This particular PCK format is made up of two elements. The first element is what we have called a CoRe (Content Representation) which offers an overview of the particular content taught when teaching a topic. The second element is what we have called PaP-eRs (Pedagogical and Professional-experience Repertoires), which are succinct but specific accounts of practice that are intended to offer windows into aspects of the CoRe. PCK representations demonstrated through a CoRe and the associated PaP-eRs combine to create a Resource Folio of PCK on that given content/topic. Such Resource Folios have been constructed by using the prompts associated with a CoRe as discussion points when working with teachers to gather the data that eventually becomes the completed CoRe and associated PaP-eRs. (Loughran, 2006, p. 21)

PCK is often a tacit feature of classroom practice since it is partly an internal construct of the teacher (Baxter and Lederman, 1999). It is a highly personalized and topic specific feature of the teacher knowledge base that differs significantly from one teacher to the next. And due its variability, Loughran et al. (2004) "sought to detect PCK through such things as: content-specific teaching procedures, such as role-plays, laboratory work, demonstrations, etc.; discussions with teachers about their teaching; classroom observation; and 'traditional' approaches to seeing 'knowledge through the practice' of experienced science teachers" (p. 373).

With this approach, a teacher's PCK can be represented by using the CoRe (Content Representation) and PaP-eRs (Pedagogical and Professional-experience Repertoires) format during the classroom observational phase of the study. The first element, CoRe, "provides an overview of how a given group of teachers conceptualize the content of particular subject matter or topic" (Loughran et al., 2006, p. 21). With CoRe, the "big ideas" of a particular topic are explored (listed on the horizontal axis, in Figures 8-14), which are then "probed and quizzed in different ways through the prompts that are listed on the left hand side vertical axis so that specific information about the big ideas that impact on the manner in which the content is taught can be made explicit" (Loughran et al., 2006, p. 21).

The PaP-eRs portion of the instrument is a "narrative account of a teacher's PCK that highlights a particular piece, or aspect, of science content to be taught" (Loughran et al., 2006, p. 24). Moreover, it is a representation of the reasoning and thought processes teachers go through as they plan and teach their lesson. By applying both CoRe and PaP-eRs in the observational phase of the study, the "holistic nature and complexity of PCK" (Loughran et al., 2006, p. 24) were documented. The resulting feature of these interactions of both CoRe and PaP-eRs is a resource folio that contains "complementary representations of successful teachers' PCK about teaching particular subject matter to a particular group of students in a particular way for very important pedagogical reasons" (Loughran et al., 2006, p. 25).

By being able to document and track episodes of PCK, the CoRe/PaPeRs instrument was an invaluable tool to evaluate the progression of PCK. As such, the instrument was used in multiple forms. First, CoRe/PaPeRs were used during the classroom observational phase of the study to objectively document PCK in action. Second, the participating teacher completed a CoRe/PaPeRs form for each lesson. The completed forms were then qualitatively evaluated regarding the status of PCK demonstrated during a lesson.

Semi-Structured Interviews

Face-to-face semi-structured interviews were conducted for each of the participating teachers in this study. The purpose of these interviews was to expand on the teacher's personal and professional growth stages of knowledge development. Narrative recollections were gathered as they relate to individual teaching practices that provided a more detailed understanding of knowledge construction. The concept of PCK, which is highly specialized and eccentric, and how teachers utilize their knowledge in their practice were questioned. Furthermore, teacher efficacy and its relationship and influence to their teaching practices were explored as well as using the CoRe and PaP-eRs instrument to assess PCK. This helped determine the learning and social interactions necessary for changes to take place in the belief structures of both teacher and student. The frequency of the interviews varied depending on the lesson conducted during observation. However, the teacher was debriefed after every classroom observation.

In addition, the Science Teaching Efficacy Belief Instrument (STEBI) was administered in the interview phase of the study to help gauge the teacher's self-efficacy levels and how variability in efficacy levels can influence both teaching and growth. Moreover, rather than numerically determining efficacy episodes, the answers to some of the questions were used to qualitatively evaluate teacher efficacy in conjunction with comments and observations made during a lesson.

Efficacy Instrument for Science Teaching

The instrument utilized to measure the efficacy levels of science teachers in this study was the Science Teaching Efficacy Belief Instrument (STEBI) developed by Riggs and Enochs (1990). The instrument consists of two scales (Personal Science Teaching Efficacy Belief and Science Teaching Outcome Expectancy) consisting of twenty five questions presented to in a Likert scale format.

> The response categories [are] "strongly agree," "agree," "uncertain," "disagree," and "strongly disagree." Scoring was accomplished by assigning a score of five to positively phrased items receiving a "strongly agree" response, a score of four to "agree" and so on throughout the response categories. Negatively worded items were scored in the opposite direction with "strongly agree" receiving a score of one. Item scores of each dimension were summed to calculate two separate scale scores for each respondent. (Riggs & Enochs, 1990, p. 628)

The instrument was given to the participating teachers as they progressed through their teaching lessons to gauge the effect teacher efficacy has on PCK as well as on their professional growth in general. Although statistical significance becomes problematic in this study due to the limited number of participating teachers, the STEBI was utilized as a qualitative indicator of self-efficacy at a particular teaching. Because the study is based on highlighting qualitative changes that occur during classroom instruction, the STEBI was used, in conjunction with interviews and classroom observations, since it was able to gauge teacher efficacy changes.

Furthermore, choosing to use the STEBI is based on the theory that it helps "teachers clarify their beliefs and to develop an organized conception of how these beliefs might be represented in behavior" (Riggs & Enochs, 1990, p. 634). This is based on the concept that the STEBI can "stimulate teachers to think about their own beliefs, attitudes, and behavior patterns [since] such self-analysis might be a valuable part" (Riggs & Enochs, 1990, p. 634) of professional growth.

Setting and Participant Selection

Pseudonyms were used for the school as well as for all participating teachers and their students for this study. The setting for this study took place at Hampshire High School, a suburban high school located near a major metropolitan city in the southwestern region of the United States. For the 2013-2014 school year, Hampshire High School (HHS) had an enrollment of over 2500 students for grades 9-12 with about 44% of the student population classified as being economically disadvantaged. Student demographics at HHS were the following: 40% Hispanic students, 30% Caucasian students, 20% African American students, and approximately 10% Asian students. Participants for the study comprised of three experienced science high teachers (one biology, one physics, and one chemistry teachers) teaching two lesson units. The subjects of this study all have at least eight years of classroom teaching experience. The assumption that classroom experience correlates with PCK means that experienced teachers already possess a sufficient base of PCK. However, experienced teachers continue to acquire and seek PCK knowledge. To better understand the processes and complexities of such growth, participants with extensive classroom teaching experience were sought out.

The recruitment of teachers for this study involved the principal asking science teachers, via electronic mail, if they wanted to participate in a study on teacher knowledge. Four teachers responded positively to the announcement (two biology, one chemistry, and one physics). After informing them of the purpose and nature of the study, all four teachers agreed to participate in the case study. However, during data collection, the decision to omit one teacher (biology/girls basketball coach) from the study was made due to several factors: the teacher not completing any of the CoRe/PaPeRs templates for his lessons, numerous absences due to extracurricular school activities, and the extended use of student reading and note taking witnessed during classroom observations which involved sparse teaching.

Data Collection

Data collection for this case study was a detailed and thorough process involving observational and instrument data as well as interviews that took place during the fall semester of the 2013-2014 school year. A total of two months of classroom observational data were collected for this study. The itinerary for data collection encompassed classroom observations with pre and follow up interviews with each participating teacher. Reflective interviews during the debriefing process consisted of the teacher completing the STEBI as well as a specified CoRe/PaPeRs template. With this, a comparison of completed templates were undertaken to assess PCK in conjunction with the level of self-efficacy during a particular teaching experience.

During classroom observations, which were audio recorded, notes and pertinent social interactions were obtained. Artifacts (student work, teacher lesson plans, etc.) and a reflective observational summary were also completed during the case study that aided in triangulating the data from the observations. For each of the participating teachers, data were collected on multiple classes (two classes for each teacher) to reflect the broad reaches of the teacher practice. This enabled the exposure of multiple student learning styles and provided the opportunity to witness the teacher practice in varying classroom conditions.

A total of two lesson units were observed for each of the participating teachers. For each teacher (pseudonyms used), two classes were observed: (1) Mr. Branson—Regular Chemistry and Pre-AP Chemistry (Stoichiometry Lessons), (2) Ms. Crawley—Regular Physics and AP Physics (Work and Energy Lessons), and (3) Ms. Dawson—Regular Biology (Animal Systems and Ecology Lessons).

CoRe/PaPeRs Instrument

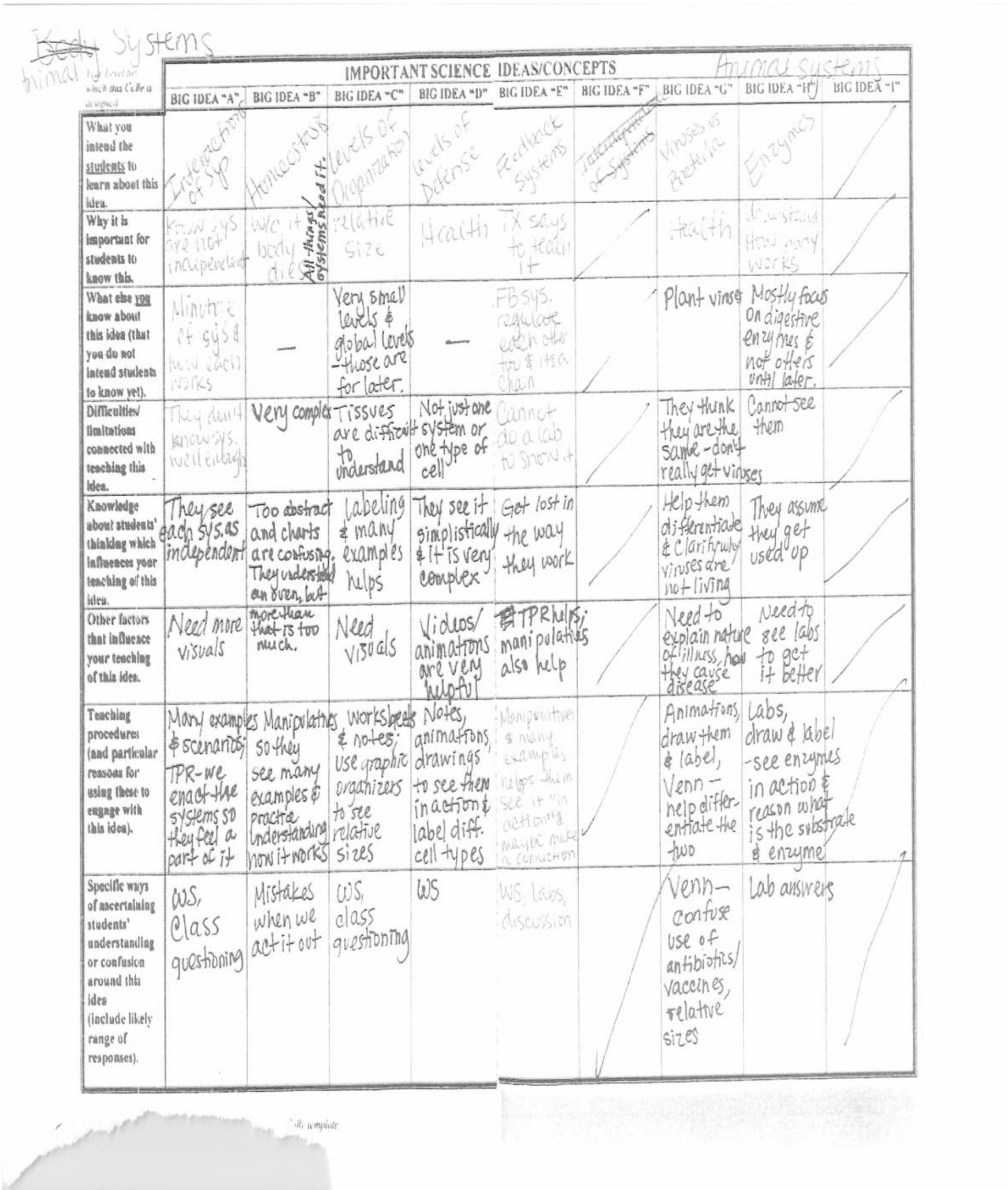
The CoRe/PaPeRs instrument was used to document episodes of PCK. For each observed class, the instrument was completed by both the observer and the participating teacher. The completed prompts from the instrument were then evaluated with one another along with reflective notes made during the observation to objectively determine relevant PCK episodes observed for each lesson. Isolating specific instances of PCK for the participating teachers results from observing how well students are able to grasp the material by being able to answer questions posed to them along with the abilities of the teachers to present material to their students (e.g. verbal and visual representations, demonstrations, laboratory exercises). Therefore, the answers to the prompts on the CoRe segment offers a snapshot of a teacher's PCK in their lesson that can be used in conjunction with classroom observations to validate if PCK was indeed demonstrated by the teacher. The PaPeRs portion of the instrument, which consists of a narrative account of the observed lesson, involves the thought and reasoning processes of the teacher during a lesson. Therefore, this aspect of the instrument was completed using the questions asked by both teacher and students during class in order to probe the thinking process of teachers. Because the PaPeRs component contains a descriptive explanation of how teachers approach a particular topic, the participating teachers encountered difficulty in completing the form. As a result, the PaPeRs portion was completed orally during the debriefing held after class with the researcher in the form of an interview. Figures 8-14 show the completed CoRe prompts from each of the three participating teachers.

PHYSICS (Energy)

Year Level for which this CoRe is designed	IMPORTANT SCIENCE IDEAS/CONCEPTS: BIG IDEA "A" (~~BIG IDEA "B"~~, ~~BIG IDEA "C"~~)	BIG IDEA "D" (~~BIG IDEA "E"~~, ~~BIG IDEA "F"~~)	BIG IDEA "G" (~~BIG IDEA "H"~~, ~~BIG IDEA "I"~~)
What you intend the students to learn about this idea.	Energy cannot be created, simply converted from one form to another	the main three types of energy are gravitational potential, kinetic, and elastic	Any lost energy goes to work being done
Why it is important for students to know this.	To be able to understand energy transformations	How to apply the equations to different situations	Explains why energy is not always the same (conserved)
What else you know about this idea (that you do not intend students to know yet).	there are very few situations in the real world where energy is truly conserved	Usually there is a combination of the three types involved	this work is usually in the form of [illegible] friction
Difficulties/limitations connected with teaching this idea.	helping kids see where the energy is coming from during these conversions (like potential to kinetic)	Identifying when to use each type of energy especially if there is more than one type involved	when is work being done Also knowing that work is just a change in energy
Knowledge about students' thinking which influences your teaching of this idea.	need to see lots of visual representations		
Other factors that influence your teaching of this idea.		equations relate past concepts like velocity	
Teaching procedures (and particular reasons for using these to engage with this idea).	Lots of demos to show energy changes in real life (pendulums, rollercoasters, etc)	~~[illegible]~~ laboratory investigations and practice problems using the different types	using graph to show work being done and expressing that as a change in energy
Specific ways of ascertaining students' understanding or confusion around this idea (include likely range of responses).	Experiments, questioning during class, quizzes, and tests		

Figure 3.1 CoRe template

Figure 8. CoRe prompts from Ms. Crawley's physics class



~~Body~~ Systems

Animal Systems

Animal / Year Level for which this CoRe is designed	BIG IDEA "A"	BIG IDEA "B"	BIG IDEA "C"	BIG IDEA "D"	BIG IDEA "E"	BIG IDEA "F"	BIG IDEA "G"	BIG IDEA "H"	BIG IDEA "I"
	IMPORTANT SCIENCE IDEAS/CONCEPTS								
What you intend the students to learn about this idea.	Interaction of Sys	Homeostasis	Levels of Organization	Levels of Defense	Feedback Systems	~~Interdependence of Systems~~	Viruses vs Bacteria	Enzymes	
Why it is important for students to know this.	Know sys are not independent	w/o it body dies; All things/systems need it	relative size	Health	TX says to teach it		Health	Understand how body works	
What else you know about this idea (that you do not intend students to know yet).	Minutiae of sys & how each works	—	Very small levels & global levels - those are for later.	—	FB sys. regulate each other & its a chain		Plant virus	Mostly focus on digestive enzymes & not others until later.	
Difficulties/limitations connected with teaching this idea.	They don't know sys. well enough	Very complex	Tissues are difficult to understand	Not just one system or one type of cell	Cannot do a lab to show it		They think they are the same - don't really get viruses	Cannot see them	
Knowledge about students' thinking which influences your teaching of this idea.	They see each sys. as independent	Too abstract and charts are confusing. They understand an oven, but	Labeling & many examples helps	They see it simplistically & it is very complex	Get lost in the way they work		Help them differentiate & clarify why viruses are not living	They assume they get used up	
Other factors that influence your teaching of this idea.	Need more visuals	more than that is too much.	Need visuals	Videos/animations are very helpful	TPR helps; manipulatives also help		Need to explain nature of illness, how they cause disease	Need to see labs to get it better	
Teaching procedures (and particular reasons for using these to engage with this idea).	Many examples & scenarios; TPR - we enact the systems so they feel a part of it	Manipulatives so they see many examples & practice understanding how it works	Worksheets & notes; use graphic organizers to see relative sizes	Notes, animations, drawings to see them in action & label diff. cell types	Manipulatives & many examples helps them see it "in action" & maybe make a connection		Animations, draw them & label, Venn - help differentiate the two	Labs, draw & label - see enzymes in action & reason what is the substrate & enzyme	
Specific ways of ascertaining students' understanding or confusion around this idea (include likely range of responses).	WS, class questioning	Mistakes when we act it out	WS, class questioning	WS	WS, labs, discussion		Venn - confuse use of antibiotics/vaccines, relative sizes	Lab answers	

CoRe template

Figure 9. CoRe prompts for Ms. Dawson's unit on animal systems

Ecology

Year Level for which this CoRe is designed	IMPORTANT SCIENCE IDEAS/CONCEPTS							Ecology	
	BIG IDEA "A"	BIG IDEA "B"	BIG IDEA "C"	BIG IDEA "D"	BIG IDEA "E"	BIG IDEA "F"	BIG IDEA "G"	BIG IDEA "H"	BIG IDEA "I"
What you intend the students to learn about this idea.	Levels of Organization	Food Chains & Webs	Energy (Trophic Levels)	Pyramids	Biogeochemical Cycles	Symbiosis	Succession	Biodiversity	Limiting Factors
Why it is important for students to know this.	Relative size	Where energy comes from & goes	How energy is lost	Relative/visual of Food chains+ Numbers & Biomass	How life interacts w/ Earth	How species interact & depend on ea other	How life comes back	Importance for survival of species	Factors that limit populations
What else you know about this idea (that you do not intend students to know yet).	Very small levels will be learned later	Barely touch on aquatic food chains	What a Joule really is. I just tell them it's a unit.	—	Phosphorus Cycle	—	—	Genetics side of it is learned later	—
Difficulties/limitations connected with teaching this idea.	No difficulties	Vocab- autotroph/heterotroph	Trophic levels- what they really are	Biomass Concept	Nitrogen cycle	Commensalism is a difficult concept	Easy topic	what diversity really is	So many to choose from & they don't get this concept
Knowledge about students' thinking which influences your teaching of this idea.	At these levels they get this easily	Already familiar		Visual of Δ helps understanding	Know water cycle & some of carbon cycle	Using symbols gives a visual they can use	They get this easily	They need more examples of what is biodiversity	Analogies help explain it
Other factors that influence your teaching of this idea.									
Teaching procedures (and particular reasons for using these to engage with this idea).	Diagrams, visuals, pictures, WS	Draw & label, WS	Draw & label, WS	Draw & label	label pictures, practice questions, WS	Practice questions, WS, Quiz, Manipulatives	Power Point pictures, practice as a class, can tell w/ class discussion	Questioning, Practice questions	WS, lab to practice seeing how it happens or game
Specific ways of ascertaining students' understanding or confusion around this idea (include likely range of responses).	WS	Grade notebooks, WS	WS	WS	WS, warm up ?'s	Warm ups, Quiz	WS	Labs	WS

Figure 3.1 CoRe template

Figure 10. CoRe prompts for Ms. Dawson's ecology unit

Unit 5 Compounds (Nomenclature) 1st Chem

Your Level for which this CoRe is designed.	IMPORTANT SCIENCE IDEAS/CONCEPTS								
	BIG IDEA "A"	BIG IDEA "B"	BIG IDEA "C"	BIG IDEA "D"	BIG IDEA "E"	BIG IDEA "F"	BIG IDEA "G"	BIG IDEA "H"	BIG IDEA "I"
What you intend the students to learn about this idea.	To Know how to correctly write & name chemical compounds.								
Why it is important for students to know this.	To understand chemical Rxns; stoicheometry & the language of chemistry								
What else you know about this idea (that you do not intend students to know yet).	Correctly writing formulas / naming enables balancing & stoich.								
Difficulties/ limitations connected with teaching this idea.	Students do not want to practice outside of the class time.								
Knowledge about students' thinking which influences your teaching of this idea.	Prior Knowledge obtained from 7th + 8th grade years + Units 2-4. district pacing calendar								
Other factors that influence your teaching of this idea.	Trying to make it as simple since they don't want to work outside of class.								
Teaching procedures (and particular reasons for using these to engage with this idea).	Taught Covalent compounds first based on past years + how students confused Ionic/covalent nomenclature								
Specific ways of ascertaining students' understanding or confusion around this idea (include likely range of responses).	Use of covalent prefixes every time.								

Figure 3.1. CoRe template

Figure 11. CoRe prompts for Mr. Branson's regular chemistry

Unit 6 Chemical RxNS 1st Chem.

Year Level for which this CoRe is designed.	IMPORTANT SCIENCE IDEAS/CONCEPTS: BIG IDEA "A", BIG IDEA "B", BIG IDEA "C", BIG IDEA "D", BIG IDEA "E", BIG IDEA "F", BIG IDEA "G", BIG IDEA "H", BIG IDEA "I"
What you intend the students to learn about this idea.	Identify & predict & balance chemical Rxns
Why it is important for students to know this.	To understand chemical equations; stoich & basis of chem
What else you know about this idea (that you do not intend students to know yet).	This is the language of the course
Difficulties/ limitations connected with teaching this idea.	It is a Domino effect; if student cannot write formulas they cannot balance
Knowledge about students' thinking which influences your teaching of this idea.	How well they write formulas -
Other factors that influence your teaching of this idea.	District pacing + prior knowledge - student effort
Teaching procedures (and particular reasons for using these to engage with this idea).	Trying to let them know how chemistry builds each unit.
Specific ways of ascertaining students' understanding or confusion around this idea (include likely range of responses).	Drill + practice.

Figure 3.1: CoRe template

Figure 12. CoRe prompts for Mr. Branson's chemical reactions in regular chemistry

Unit 5 Nomenclature Zero PAP Chem

Year Level for which this CoRe is designed	IMPORTANT SCIENCE IDEAS/CONCEPTS								
	BIG IDEA "A"	BIG IDEA "B"	BIG IDEA "C"	BIG IDEA "D"	BIG IDEA "E"	BIG IDEA "F"	BIG IDEA "G"	BIG IDEA "H"	BIG IDEA "I"
What you intend the <u>students</u> to learn about this idea.	To write & name chemical compounds								
Why it is important for students to know this.	Understand chemical RXNS; Stoich & basic chemistry								
What else <u>you</u> know about this idea (that you do not intend students to know yet).	Correctly writing formulas / naming enables balancing & stoich.								
Difficulties/ limitations connected with teaching this idea.	Students do not want to practice outside of class time								
Knowledge about students' thinking which influences your teaching of this idea.	Prior knowledge & district pacing calendar								
Other factors that influence your teaching of this idea.	Student efforts								
Teaching procedures (and particular reasons for using these to engage with this idea).	Taught covalent 1st based on students mixed ionic with covalent								
Specific ways of ascertaining students' understanding or confusion around this idea (include likely range of responses).	Drill practice & constant reminders								

Figure 3.1: CoRe template

Figure 13. CoRe prompts for Mr. Branson's nomenclature unit for pre-AP chemistry

Unit 6 Chemical Reactions Zero PAP Chem

Year Level for which this CoRe is designed	IMPORTANT SCIENCE IDEAS/CONCEPTS								
	BIG IDEA "A"	BIG IDEA "B"	BIG IDEA "C"	BIG IDEA "D"	BIG IDEA "E"	BIG IDEA "F"	BIG IDEA "G"	BIG IDEA "H"	BIG IDEA "I"
What you intend the students to learn about this idea.	Identify predict products + balance Chemical RXNS.								
Why it is important for students to know this.	To understand chemical equations; stoich + basics of chemistry								
What else you know about this idea (that you do not intend students to know yet).	This is the language of chemistry								
Difficulties/ limitations connected with teaching this idea.	If students cannot write formulas they cannot balance.								
Knowledge about students' thinking which influences your teaching of this idea.	How well they write formulas								
Other factors that influence your teaching of this idea.	District pacing + prior knowledge Student effort								
Teaching procedures (and particular reasons for using these to engage with this idea).	How chemistry builds with each unit								
Specific ways of ascertaining students' understanding or confusion around this idea (include likely range of responses).	Drill + practice								

Figure 3.1. CoRe template

Figure 14. CoRe prompts for Mr. Branson's chemical reactions in pre-AP chemistry

STEBI Instrument

The STEBI instrument was administered to help validate episodes of teacher efficacy during the observational period. Due to the low number of participants in this study, a quantitative evaluation was not a valid approach of measuring teacher efficacy levels. Therefore, the method of using the STEBI was modified for this study. First, through classroom observations, incidences of efficacious behavior, such as addressing student misconceptions and successful questioning of students, were noted for each teacher. On these particular lessons where teacher efficacy was determine to be present through observations, specific responses to questions on the STEBI were examined to verify if the teacher did, indeed, display teacher efficacy. In particular, teacher responses to the personal science teaching efficacy belief (PSTE) questions were examined (questions 2-5, 6, 8, 12, 17-19, and 21-24), which relate to the teacher's self-efficacy while teacher efficacy (science teaching outcome expectancy) was observed through classroom observations. As a result, instead of tabulating a numerical score of teacher efficacy, results from the STEBI were used to filter and validate incidents of efficacious behavior observed during a lesson. So if the results of the STEBI coincided with observed instances of teacher efficacy then that particular lesson was chosen to be part of the study. Therefore, the STEBI was used to validate observed instances of teacher efficacy levels during a lesson by acting as a filtering agent.

The following calendar (see Figure 15) indicates episodes of teacher efficacy that were documented through classroom observations and the STEBI for the participating teachers. Such incidences of teacher efficacy were chosen and used for this study.

October 2013				
Monday	Tuesday	Wednesday	Thursday	Friday
7	8	9	10	11
14	15	16	17	18
21	22 First day of data collecting	23 STEBI chemistry: nomenclature	24	25
28 STEBI physics: displacement, work, power	29 STEBI physics: kinetic energy	30	31 STEBI chemistry: mole introduction	

November 2013				
Monday	Tuesday	Wednesday	Thursday	Friday
				1
4	5	6 STEBI physics: pulley	7	8 STEBI chemistry: oxidation reduction
11	12	13 STEBI chemistry: chemical reactions	14	15
18	19 STEBI physics: simple harmonic motion	20	21 STEBI physics: free fall calculations	22
25	26	27	28	29

Figure 15. Calendar of days indicating episodes of teacher efficacy

December 2013				
Monday	Tuesday	Wednesday	Thursday	Friday
2	3	4 STEBI physics: roller coaster lab	5	6
9	10	11	12	13 last observational day

Figure 15. Calendar of days indicating episodes of teacher efficacy

Participating Teachers (Pseudonyms Used)

Mr. Branson

Mr. Branson is a chemistry teacher who has been teaching for the last 14 years at Hampshire High School (HHS). An 18 year teaching veteran, Mr. Branson teaches several sections of chemistry and Pre-AP chemistry to sophomores. The two classes observed include a regular section of chemistry and a section of Pre-AP chemistry. Both classes followed a similarly scheduled curriculum and so a complete lesson on stoichiometry, which included a lesson on nomenclature and a lesson on chemical reactions. The disparity between the regular and Pre-AP chemistry sections was found in the chemical reactions lesson whereby the Pre-AP students were taught a more complex set of reactions (e.g. second and third level chemical reactions).

For Mr. Branson, who has a science composite teacher certification as well as undergraduate degrees in biology and communications, his veteran status has made him into a mentor teacher helping pre-service and induction year teachers get acclimated to teaching. He has been teaching the physical sciences throughout his time at HHS, having begun teaching Integrated Physics and Chemistry (IPC) for the first few years at HHS.

Mr. Branson's classroom resembled a typical high school chemistry room, with a laboratory section that occupied about half the classroom space. Student desks were arranged in vertical groups facing Mr. Branson's desk, next to the front white board. At the start of each class, Mr. Branson would have a warm-up question for the class displayed on the front screen projector.

Ms. Crawley

Ms. Crawley, who holds an undergraduate degree in biochemistry and underwent alternative teaching certification, has been teaching physics throughout her eight year career all at HHS. She teaches several regular sections of physics and AP physics to juniors. One section of regular physics and one section AP physics were observed. For both classes, lessons on work and energy were observed

Ms. Crawley's classroom is equipped with laboratory facilities located on one side with the other side taking up student desks. Unlike regular classrooms, students' desks are separated into two groups positioned on both sides of the classroom. A walkway separates the two groups of students, who are sitting so they are facing each other, allowing Ms. Crawley a walkway from one end to the other end of the classroom.

Like Mr. Branson, Ms. Crawley begins every class with a warm-up question displayed on a projection screen that is relevant to the day's lesson. When it is time to discuss the warm-up question and began the lesson for the day, Ms. Crawley's walkway is constantly used as she paces from one student to the next.

Ms. Dawson

Possessing an undergraduate degree in biology and having completed a university-based teacher certification program, Ms. Dawson is a biology teacher at HHS. Having spent her entire eight year teaching career at HHS, Ms. Dawson teaches several sections each of regular and English as a Second Language (ESL) biology to freshman students. Ms. Dawson is also bi-lingual with a fluent understanding of Spanish due to having time spent in Latin America during her youth.

Lessons observed in Ms. Dawson's classes included animal systems and ecology. Two sections of Ms. Dawson's regular biology classes were observed. Unlike the other participating teachers, Ms. Dawson does not have an established classroom, she is colloquially called a "floater," because she has to go to separate classrooms for each of her classes. A similar observation seen in the other teaches was also seen in Ms. Dawson's classes, the use of a warm-up question to start the class. The question, relevant to the day's lesson, is displayed on a projection screen for the students to complete.

Validity and Reliability

"The validity of findings or data is traditionally understood to refer to the 'correctness' or 'precision' of a research reading" (Lewis & Ritchie, 2003, p. 273). For this case study, a construct validity test was performed to validate the findings and data. First, data from three sources were collected from the study from several qualitative instruments that established the necessary "chain of evidence" (Yin, 2003) to help in the triangulation of data. Second, the findings were member checked by the participating teachers during their exit interviews after data collection was finished.

The reliability deals with the "replicability of research findings and whether or not they would be repeated if another study, using the same or similar methods, was undertaken" (Lewis & Ritchie, 2003, p. 270). For this qualitative study, reliability was not an issue of concern due to the following: (1) the selection of the subjects for the study was without bias, (2) fieldwork for the study was carried out consistently, (3) data analysis was performed from multiple sources that aided in triangulating data, and (4) the design of the study and subsequent analysis of the data permitted differing perspectives to be identified (Lewis & Ritchie, 2003, p. 272).

Data Analysis

Classroom observations, which were audio recorded using a wireless digital receiver, were manually transcribed to better interpret the data. The transcribed recordings were then grouped according to class and lesson for each participating teacher. Coding procedures for the transcribed set of observations included highlighting episodes of PCK and teacher efficacy in action. Particular attention was paid to teacher-student interactions that occurred during lessons.

The classroom observation transcriptions were coded according to the two themes of the study: PCK and teacher efficacy. When effective demonstrations of PCK and/or teacher efficacy were observed (through an analysis of the CoRe/PaPeRs and STEBI instruments along with reflective notes made during the lesson), those sections were selected for further study. The verbal interactions that occurred in the selected sections were further scrutinized to help localize uses of PCK and teacher efficacy for the study.

The frequency of the interviews varied for each participating teacher depending on effective demonstrations of PCK and teacher efficacy during a lesson. Typically, weekly interviews were conducted for duration of the study with some additional interviews consisting of pre and post lesson teaching questions. For each weekly interview, the participating teachers completed a STEBI form. Coding procedures were used to dissect the relevant responses pertaining to the study: development of the teacher knowledge base and the teacher's cognitive belief structures on teaching and learning. Responses during the interview were grouped according to related topics and themes that are related to PCK and teacher efficacy as they occurred in the teachers' classrooms. Further questions about particular lesson strategies and approaches to teaching a particular topic were also asked of each participating teacher. Therefore, interviews were used to supplement data collected during classroom observations.

The CoRe/PaPeRs instrument was used for each observed class for this study. The purpose for using this particular PCK instrument was to identify uses and demonstrations of the teacher's PCK. Levels of PCK demonstrated during an observed lesson was objectively graded using the CoRe/PaPeRs template along with reflective notes taken during the observed lesson. Thus the CoRe/PaPeRs instrument was used as a filtering agent to seek out effective PCK enactments in classes observed.

The reason for using the STEBI instrument was to gauge the teacher self-efficacy levels during the course of the study. The completed instruments were not tabulated numerically due to the results not being statistically significant, due to the low number of participating teachers. However, answers to the questions on the STEBI instrument were used to support episodes of teacher efficacy observed during the observational period. Like the CoRe/PaPeRs instrument, results on the STEBI were used to filter through the classroom observational data to discover teacher efficacy representations observed during a lesson. Overall data collected from interviews and classroom observations, including pertinent artifacts, were triangulated with the two instruments to help determine the relationship and role of teacher efficacy in the process of teacher knowledge growth.

CHAPTER 4: RESULTS

Introduction

The results of the qualitative data collected are chronicled and described in this chapter. The five major components of Magnusson et al.'s (1999) model of PCK for science teaching (orientation to teaching science, knowledge of science curricula, knowledge of assessment of scientific literacy, knowledge of instructional strategies, and the knowledge of students' understanding of science) were used to evaluate the nature and status of the teachers' PCK as well as pinpoint their strengths and weaknesses in their teacher knowledge base.

Results

The central premise for this study revolves around the developmental evolution of PCK in experienced science teachers and how teacher efficacy contributes to its growth. Because PCK is an abstract and highly individualist attribute of the teacher knowledge base, teachers would possess a distinct knowledge set that is salient to their individual practices in the classroom. The continued progression of PCK in experienced science teachers lies in the vicissitudes of teacher knowledge development as it adjusts to contextual changes in the classroom. So according to the cognitive theory of conceptual change (Posner et al., 1982), teachers, aided by an efficacious environment, undergo an alteration in their belief system that results in raising their individual PCK.

This exploration of the nature of PCK hinges on fully understanding the various components of the model of PCK for science teaching (Magnusson et al., 1999) and how it is impacted by teacher efficacy. Thus this chapter provides the results necessary to answer and expound on the following research questions:

1. Does PCK evolve over time among experienced science teachers? If so, how? And how does classroom experience contribute to PCK development?
2. Does teacher efficacy among science teachers enhance the development of PCK? If so, how?

Research Question #1- *Does PCK evolve over time among experienced science teachers? If so, how? And how does classroom experience contribute to PCK development?*

Mr. Branson (Chemistry)

An 18 year veteran physical sciences teacher, Mr. Branson teaches chemistry and pre-AP chemistry to sophomores at Hampshire High School (HHS). Having taught at HHS (14 years) for the majority of his teaching career, Mr. Branson has developed into a master teacher who helps novice teachers become acclimated into the classroom. Due to his almost two decades of teaching experience, Mr. Branson's PCK has grown and matured. However, this does not mean that the growth of Mr. Branson's PCK has stalled. On the contrary, his collective teacher knowledge base, particularly PCK, continues to undergo growth manifestations enabling his practice to be both innovative and effective every year. This continuous development of PCK is a reflection of Mr. Branson's teaching practice as it adapts to the changing learning environment in the classroom.

Thus for Mr. Branson, his PCK levels has undergone significant gains as his pedagogical skills and content knowledge became acclimated to the changing learning environment over the years. Mr. Branson states that this was the result of his experience in teaching a diverse group of students with different learning styles.

Orientation to Teaching Science

For Mr. Branson, whose overall teaching approach can be categorized as being teacher-centered, his practice is centered on a combination of a didactic and academic rigor style of teaching (Friedrichsen et al., 2011). The primary teacher-centered orientations, didactic and academic rigor, are defined as the "teacher present[ing] information, generally through lecture or discussion" and the teacher challenging student through "laboratory work and demonstrations" (Magnusson et al., 1999, p. 101).

This general characterization aptly describes Mr. Branson's approach towards teaching. The observational phase of the study involved Mr. Branson's lessons on chemical reactions, whereby nomenclature and molecular equations were introduced to the students for the first time. The overall lesson structure consisted of a warm-up question and its explanation to begin the class. The format then shifts into introducing the lesson for the day with Mr. Branson presenting relevant information through PowerPoint slides. During the lesson, questions and sample problems about the topics are given to ensure student understanding.

This broad generalization of Mr. Branson's typical lesson recognizes pertinent aspects of a didactic teaching style as it relates to science teaching. The hallmark of a didactic orientation to teaching is to "transmit the facts of science" (Magnusson et al., 1999, p. 100) where lessons, inherently, become a lecture-style presentation of the daily topic. Information and facts are visually presented by way of overhead PowerPoint slides and the lesson proceeds with Mr. Branson explaining the contents of each slide.

However, because of Mr. Branson's past teaching experience, which is the culmination of teaching and knowing thousands of students, his orientation to teaching becomes malleable and adapts to the changing circumstances in the classroom. For example, even though his usual teaching style is didactic, Mr. Branson would revert to an academic rigor orientation on particular topics that the students find challenging. This was observed numerous times during the nomenclature and chemical reactions units where Mr. Branson would, during his daily lectures, introduce problems to help students better understand the topic.

The following excerpt illustrates Mr. Branson's awareness of student understanding and malleability in his teaching orientation: As Mr. Branson begins his lecture on chemical synthesis and decomposition reactions, he introduces a set of equations to solve and the steps needed to solve them. The problems were projected for the entire class to see. As he went through the first two problems, there was an active discussion between Mr. Branson and his students and the problems were solved correctly. However, with the third question, when it was time to answer the usual questions presented by Mr. Branson, there was a general silence in the room.

> Next one, magnesium oxide reacts with carbon dioxide. Metal oxides and carbon dioxides? What do all metal oxides and carbon dioxides make? [silence] What are your decomposition rules, you have it go backwards.

> So what do all metal oxides and carbon dioxides make? [silence] You should probably be looking in the notes pages 4, 5, and 6 right about now. Metal carbonates. What do they do? Ok I'll put it on the board. Metal is magnesium oxide and is MgO and carbon dioxide is CO_2 that is going to make magnesium carbonate. Look at my oxygens, 2 and then 3. I have one magnesium and one carbon, and there another one over here (point to reactant side of equation) so it this a balanced equation just like it was written? [Student response] Yes. Yes and that would be your answer.

Transitioning from a didactic teaching style to that of academic rigor is the result of Mr. Branson's knowledge of student understanding. Because academic rigor is characterized as challenging students with "difficult problems and activities [that] are used to verify science concepts" (Magnusson et al., 1999, p. 101), Mr. Branson introduces a more difficult problem (magnesium oxide reacting with carbon dioxide) for his students to solve. He asks the class about knowing the decomposition rules and how that can be applied in solving the problem at hand. So for Mr. Branson, his academic rigor orientation results in a deeper probing of the topic allowing students to comprehend the universal applicability of the rules of chemical reactions.

Throughout his daily lectures, Mr. Branson's questioning is omnipresent. Students are questioned about whether or not they understand the material being presented and given sample problems to solve, with Mr. Branson carefully explaining each step in the process. However, if the appropriate response is not given, as a result of the students not fully understanding, Mr. Branson's adjusts his teaching style accordingly. The lecture-style presentation changes into a problem solving session where more complex problems are introduced to highlight relevant chemical concepts. It is during these sessions that Mr. Branson pinpoints student deficiencies and addresses concerns raised by students.

The following illustrates an example of Mr. Branson attempting to mitigate student concerns about a particular topic: At the start of the chemical reactions unit, students in the pre-AP chemistry section were introduced to the concept of balancing chemical reactions. During the note-taking portion of the class, Mr. Branson listed a series of steps to help students comprehend the procedural rules on balancing chemical reactions (e.g. writing unbalanced equation and then balancing the equation). However, as Mr. Branson explains the individual steps, questions arose about the nature of coefficients and the states of various elements (gaseous vs nongaseous) as it relates to balancing. Students had encountered problems distinguishing between monoatomic and diatomic elements in balancing chemical reactions. As a result, Mr. Branson took time to address the role of diatomic elements by identifying them and introducing a mnemonic so that students know the seven diatomic elements (hydrogen, nitrogen, oxygen, chlorine, bromine, iodine, and fluorine):

> Remember your diatomic elements, because if those seven special elements are by themselves, they have to have a subscript too. What are those seven special elements? Seventh Heaven and BRINCLe-HOF [seven elements/Br_2, I_2, N_2, Cl_2, H_2, O_2, F_2]. You cannot change a subscript. Once you have number one done [writing the unbalanced equation], you cannot change a subscript, you change the subscript, you change the formula and if you change the formula you change the equation. So once you have step one done, the only thing you can do is change the big number out in front of the formula, that is the coefficient.

This exchange was then followed by going over various unbalanced equations. Once the discrepancies between various elements were rooted out, students were able to successfully balance a series of chemical reactions that highlighted the difference between coefficients of various compounds, including diatomic elements.

This complementary use of different teaching orientations is the result of Mr. Branson's expanding knowledge of understanding and anticipating student understanding and reactions. Over the years of teaching chemistry, Mr. Branson has come to comprehend common misconceptions and mistakes students make on particular topics. For example, with balancing chemical equations, Mr. Branson points out to his class that previous students tend to break the unbalanced formula apart to its separate compounds resulting in an incorrect answer to the problem.

It is the change in the teaching style, albeit the same teacher-centered orientations, that has evolved over the years, according to Mr. Branson. Grossman (1990) posits four possible avenues for PCK to develop: (1) apprenticeship of observation, (2) disciplinary background, (3) professional coursework, and (4) learning from experience. For Mr. Branson, his experience in the classroom, both personal and professional, has made an indelible impression that has steered him towards the "traditional" approach to teaching. As a result, Mr. Branson comments that his initial approach to teaching was the didactic method that was prevalent during his days as a student.

However, as his exposure to students increased, Mr. Branson underwent a cognitive growth phase that made him realize differences among students. Prior to coming to teach at HHS, Mr. Branson's first teaching experience was at a small rural school whose students were predominately minority and underprivileged. Being exposed to such a diverse group of students made Mr. Branson realize the growth potential and limitations of student learning. He states that being "straightforward and direct" with his students has been the most successful way of communicating and understanding students. So by knowing more about his students' learning tendencies, Mr. Branson had come to the realization that his teaching style needs to be flexible enough to accommodate different student populations and that his teaching should be adaptable to the situation at hand. Therefore, because chemistry, especially stoichiometry, can be an abstract topic for students, Mr. Branson's cognitive growth over the years has made him aware of the different learning needs of students, which, in turn, changed his belief structure of how to best address those concerns.

Knowledge of Science Curricula

Having been a teacher in the same school for the past 14 years, Mr. Branson's knowledge of the science curriculum has fully developed as he is aware of both district and state mandates as well as various programs and materials relevant to the teaching of chemistry. In the model of PCK for science teaching (Magnusson et al., 1999), the knowledge of science curricula includes two critical components: the knowledge of goals and objectives and the knowledge of specific curricular programs.

In regards to the knowledge of goals and objectives in the field of chemistry, the primary objective is the comprehension of scientific concepts and processes. For the two units that were observed, nomenclature and chemical reactions, the main goal for the lessons was to educate students to recognize and quantify elements in chemical reactions. When asked about the objectives for both units, Mr. Branson, being aware of the goals, states stoichiometry allows students to comprehend the “language of chemistry” which, in turn, will provide the foundation necessary to grasp the principles of chemistry for future lessons.

The second aspect of the science curricula knowledge pertains to the knowledge of specific curricular programs. As an experienced chemistry teacher, who has taught the same course for many years, Mr. Branson has come to realize the need to supplement his practice with various existing curriculum materials to best handle the learning needs of his students. As a result, in lieu of using the district approved textbook, Mr. Branson has, over the years, supplemented his lessons with a variety of materials that match his teaching philosophy including personally made notes for students as well as an online resource (e.g. Sapling Learning, which contains interactive modules tailored to each daily lesson) that complements his lessons.

The overall basis for the knowledge of science curricula, therefore, becomes an extension of Mr. Branson’s orientation to teaching since it reflects on his general perception of how to best teach his students. Mr. Branson’s cumulative classroom experience has provided him with the opportunity to witness the response of his students to certain curriculum materials. Successful integration of such supplemental material to his practice has allowed Mr. Branson to complement his style of teaching with his knowledge of the science curriculum. Thus this interrelationship that exists between teaching orientation and knowledge of science curricula reveals how a teacher’s approach and style to teaching can be heavily influenced by the teacher’s knowledge of the curriculum.

Knowledge of Students' Understanding of Science

This component of the model of PCK concerns the teacher's overall understanding of students in the classroom setting. With its two constituents (knowledge of requirements for learning and the knowledge of areas of student difficulty), this aspect of a teacher's PCK embodies the type of relationship the teacher has with his students. For this knowledge base to thrive, the teacher must be amenable to establishing a personal rapport with individual students in order to root out learning strengths and weaknesses.

Mr. Branson states that his teaching experience has exposed him to a diverse group of students over the years that made him recognize various learning styles (e.g. visual, verbal, intrapersonal, interpersonal, etc.) and ability levels of students. According to Mr. Branson, his belief structure concerning student behavior and learning has gradually undergone modifications to better accommodate student differences. He states the need to be "nurturing" to his students so they can become acclimated to the learning environment in his classroom. He continues by stating that "it depends on where my kids come from (background)," describing the familial and socio-economic situations as critical in better understanding their learning tendencies, especially their prior knowledge and skills.

When asked to expound on how he came to realize student differences and the most resourceful way of addressing them, Mr. Branson points to his prior teaching experience, especially his initial years as a teacher. Prior to coming to HHS, Mr. Branson spent the first three years teaching in two different schools in another state. His first year of teaching placed Mr. Branson at a low socio-economic rural school whose students were predominately African-American. This was followed by a stint at a much larger suburban school with a student population opposite to that of the rural school (high socio-economic students and very few minority students). This variability in the student population has provided Mr. Branson the opportunity to experience the entire spectrum of student differences.

As a result, he has developed a tenet in his teaching ideology to place a greater importance on learning more about his students in order to optimize their learning experience. During the observational period, Mr. Branson was frequently seen engaging in conversation with his students. This desire to personally know each of his students builds a relational foundation that allows both student and teacher to have a certain comfort level that is needed to root out learning discrepancies and approaches during class. Moreover, Mr. Branson has come to learn the benefits of knowing more about his students' individual tendencies so that he can fashion his lesson appropriately. He states that now "it takes about three weeks" for him to fully grasp and understand each of his students, carefully observing student reactions and comments during class. For Mr. Branson's PCK, it is this aspect, student understanding, that continues to be the driving force for his growth due to having a new group of students every year.

Due to the diverse nature of student learning that he is exposed to every year, Mr. Branson states that he "has to adjust" to better accommodate his students. This highlights the association between his teaching orientation with the general knowledge of student understanding as it influences his approach to lesson planning. Although his general orientation to teaching has gravitated towards a teacher-centered approach that is "very structured," in terms of how to approach and solve chemical problems, Mr. Branson takes the time and effort to ensure that all of his students have the opportunity to learn. For stoichiometry, he states that "constant repetition of procedures" has been the most fruitful method for students in acquiring the skills to tackle the chemical problems. If questions about a particular lesson arise and learning becomes problematic, which he is able to detect by way of his questioning during class or by identifying mistakes made on homework assignments, Mr. Branson "stops everything and go back and talk to them (students) about what is expected."

It is this productive knowledge of students, getting to personally know individual students and establishing a meaningful relationship, which is central for Mr. Branson's growth in the knowledge of student understanding thereby increasing his PCK year in and year out. This is the result of having to know and understand a different group of students at the beginning of every school year. He becomes aware of his surroundings and role not only as a teacher but a mentor to his students. His comfort and subsequent efficacy levels in the way he interacts is the result of establishing a bond with students that allows Mr. Branson to respect and treat his students as individuals rather than as a collective group.

Furthermore, this knowledge of student understanding carries over to his daily lessons. Because chemistry, especially stoichiometry, is often very abstract for students to grasp the fundamental principles, student difficulty becomes a common occurrence. During the observational period, two examples of student difficulty were recognized and addressed by Mr. Branson: clearing up student misconceptions and formulating problem solving skills.

One student misconceptions, the concept of the mole (Avogadro's number) was observed and discussed by Mr. Branson. On the introductory lesson on the mole, Mr. Branson begins with the following:

> The mole. What is it? It is a counting number, it's also known as the chemist's dozen. It's also known as Avogadro's number. Here is what a mole is [pointing to PowerPoint slide]. One mole is equal to 6.02×10^{23} items, because there are several different units that we will associate with Avogadro's number. One of those units would be molecules, so you can say one mole is equal to 6.02×10^{23} molecules. You can say one mole is equal to 6.02×10^{23} formula units. You can say one mole is equal to 6.02×10^{23} ions. You can say one mole is equal to 6.02×10^{23} molecules. So it's a counting number for chemists. It's an extremely large amount so to give you an idea of how large it is, if you have one mole of hockey pucks, that would be equivalent to the mass of the Moon. If you have one mole of basketballs, that would fill a bag equivalent to the size of the Earth. If I had one mole of pennies that would cover the Earth one-quarter mile deep. So 6.02×10^{23} is a huge number, right? That ought to make sense because in chemistry you're talking about elements and small tiny things. Can you see atoms with your eyes? No. That's why we use this number, we need a number to represent large quantities.

The use of representing both microscopic and macroscopic scales to define Avogadro's number provides the students a method to gauge the difference and scope of the mole. In addition, the way Mr. Branson introduces the mole as a "counting number" allows his students to differentiate the mole as being a number rather than treating it as a mass of something.

Another misconception example observed concerns the role of reduction-oxidation (redox) reactions. With the redox lesson, a common misconception students had is the idea that oxygen (e.g. oxide) is inherently involved in such reactions. This common mistake is mainly due to the name (the "oxi" in oxidation). In addition, because redox is associated with the transfer of oxygen molecules in the formation of oxide, some students innately perceive and equate oxygen with the term oxidation rather than the transfer of electrons. To address this, Mr. Branson introduces a mnemonic to his students:

> So we have some mnemonics for you. OIL RIG [oxidation is losing, reduction is gaining] and LEO the lion says GER [losing electrons in oxidation and gaining electrons in reduction]. Oxidation is lost, which means that an element that is oxidized is going to lose electrons, so are they going to be more negative or more positive? [Jane, student, answers: positive] More positive because elements have what charge have naturally? [Robert, student, answers: zero] Reduction is gaining electrons so they are going to become more negative. If I lose electrons, it will become more positive and if I gain electrons it will become more negative.

The introduction of the mnemonic coupled with the emphasis of electron transfer alleviated the misperception surrounding the redox connotation after Mr. Branson went through several successful examples with the class. Mr. Branson followed this with numerous working examples of redox reactions that deracinated student thought from solely focusing on the oxygen element.

In the area of chemical nomenclature, Mr. Branson's lesson on naming molecular compounds is an example of his "structured" and "linear" way of thought in formulating the correct steps to approach and tackle a problem:

> Rules concerning the naming of molecular compounds. So the first rule: If the first word of the formula only has one atom, you cannot use mono. So in other words, when we go to the names the first word will never contain mono. It contains all the other prefixes but never mono. The

> first word of the name. The second atom, or monoatomic ion, must end in IDE and must use a prefix. So you will see monochloride, difluoride, trioxide, tetrafluoride, pentachloride, hexachloride, heptoxide. Must end in IDE and you have to have a prefix regardless of the count. Next, if your element name starts with a vowel, you drop the O and the A, the I does not drop ever.

This was followed by a series of practice problems with Mr. Branson leading the questioning and going through the process (based on his three rules). For Mr. Branson, the practice and drilling of procedural rules becomes critical in establishing the framework and foundation of learning for future lessons. This is the result of his prior teaching experience, realizing and taking into account the student thought processes. Examples were probed with the entire class and slowly moved into students independently naming various compounds of increasing difficulty, with Mr. Branson observing and questioning each step in the procedure.

Knowledge of Instructional Strategies

The knowledge of instructional strategies, which encompasses the teacher's beliefs and approach to teaching, can be considered to be an extension of the teacher's orientation to teaching. This was the case for Mr. Branson, who believes that for students to excel in chemistry, they must be prepared to have a proper foundation to build their analytical skills. For Mr. Branson, the foundation of learning in chemistry is based on the "traditional" approach to problem solving: understanding the rules and procedures. Comparing the learning of chemistry to building a house, Mr. Branson states the "the foundation is the support structure of the house" and that if the foundation is not properly set “the house will crumble.” This analogy appositely describes Mr. Branson’s teaching philosophy, to teach and indoctrinate students into “learning the language of chemistry.”

This overall strategy of teaching the proper rules and procedures in solving problems extends to Mr. Branson’s approach in topic-specific matters in chemistry. During the stoichiometry section, numerous rules were given to students in order to provide them with, essentially, a step-by-step map of formulating and computing answers. Examples, including nomenclature and chemical reaction rules, were stressed along with the frequent use of mnemonics and visually representations (especially the students’ online resource, Sapling Learning) to teach students that chemistry “builds with each successive unit,” implying to students that such a strong “foundation” is a necessary prerequisite to better understanding the science of chemistry. As an experienced teacher, Mr. Branson has come to identify areas of student difficulty resulting in the use of “rules” to approach certain problems. Therefore, this “linear” and “straightforward” use of rules and procedures to tackle chemistry problems have facilitated his belief that this general tactic of teaching is one that is most conducive for students to comprehend the material.

Knowledge of Assessment of Scientific Literacy

The assessment of scientific literacy is a branch of a teacher’s PCK that is utilized to ensure learning objectives are met by students. In Mr. Branson’s class, various assessments tools were observed that provided the input necessary to gauge the learning levels of his students. During the lecture portion of his lesson, for example, constant questioning became a prevalent aspect of Mr. Branson’s approach to measuring whether or not his students were able to grasp the material being presented. It was during the questioning and answering portion of his lessons that provided Mr. Branson with the information needed to measure student learning. Whether it was an incorrect answer or general silence to his questioning, Mr. Branson has, over the years, come to interpret such responses as a personal message of not "getting through" to his students. In such cases, Mr. Branson would "completely stop everything" and begin stressing the fundamental principles of his lesson by reconstructing his lessons appropriately. Examples include the introduction of mnemonics as well as giving real-world representations to topics discussed during the lesson (e.g. the mole concept and oxidation-reduction reactions). In some instances, Mr. Branson would take advantage of his relationship with his students through the use of humor and personal stories that uplifts the lugubrious state of his class on difficult topics (which was observed during the teaching of single and double replacement reactions).

In addition, the advent of technology has allowed Mr. Branson to use an online resource, particularly the use of the Sapling Learning program, for assessment. The Sapling program contains useful interactive modules and questions that concurrently serve as homework projects that Mr. Branson assigns. The program allows him to monitor student progress, in real time, and to address deficiencies encountered by his students the following day in class.

Ms. Crawley (Physics)

Entering her eighth year as a teacher, Ms. Crawley teaches physics to juniors at Hampshire High School (HHS). Having spent her entire teaching career at HHS, Ms. Crawley has developed into an effective teacher, having recently received the school district's STEM teacher of the year award. As a result, her PCK has grown significantly over the years and still continues to develop. Having a scientific background prior to entering the teaching profession, Ms. Crawley's heightened knowledge of the subject matter has provided her with the opportunity to teach physics at the advanced placement (AP) level along with regular physics. The units observed in Ms. Crawley's classes include lessons on the concept of work and power.

Orientation to Teaching Science

For Ms. Crawley, her growth in PCK is focused on discovering and learning new activities to present to her students. Her orientation to teaching science has developed into an activity-driven venture that allows her students to actively experience wonders of physics. This activity-driven orientation, which is characterized as having students "participate in 'hands-on' activities for verification or discovery," (Magnusson et al., 1999, p. 101) has allowed Ms. Crawley to infuse an active interest among her students.

According to Ms. Crawley, who possesses a biochemistry degree and obtained her teaching credentials through an alternate certification program, her initial years of teaching were a transitional period of growth. In addition to the customary "growing pains of new teachers" in managing students for the first time, Ms. Crawley had to re-learn the subject matter content. Asked about her teaching style during her first year of teaching, Ms. Crawley replied that it was the “usual lecture and note-taking style” that predominated her lessons. But as she acclimated herself into the role of being an educator, Ms. Crawley “felt the need to change” her approach to teaching. Rather than have her students sit and take notes for the duration of the class period, Ms. Crawley came to realize such a didactic approach to teaching physics did not promote the conducive learning environment she desired in her class. She states that the primary factor that necessitated her to “change” her approach to teaching was the result of her observing student reactions and responses to her teaching. “I was boring,” Ms. Crawley candidly admits to the way she taught.

As a result, she has reformulated her teaching orientation that emphasizes involving students in a more active fashion. During a typical lesson observed, the format of her lesson and her general approach to learning exemplifies constant student participation and input. The lesson starts with a warm-up question relevant to the day’s lesson. After discussing the warm-up question (a question related to the day’s lesson), the lesson shifts into a brief class discussion with Ms. Crawley’s questioning becoming a constant presence. The following exchange, observed during the lesson on work, provides such an example:

> So when you hear the term work, Michael [student] what do you think of when you hear the term work? When someone is doing work? [Michael replies] Something active? Ok. Anybody else? When you hear the term work? [students give various answers] Force? Effort? Activity? Ok. The formal definition of work is a force applied over a distance. It is making an object move by applying a force. So it’s not like I went to work and worked 10 hours in a restaurant. This is having to apply a

> force and moving something. And the key here is that the force being applied must be in the same direction that our movement is in. So the force applied has to be in the same direction. So it's the force applied to make the object move. So if I'm holding up my book and I'm walking across the room, do you think I'm doing work? Yes or no? So Brian [student] what would make me do work? How am I doing work right now? Chris [student] in which direction is my force being applied? Upwards ok. James [student] in which way am I moving? Forward. So think again, am I doing work on the book? [class responses] It's not parallel right? So my force applied is in the Y direction but my movement is in which direction? The X direction. So no work being done. Ester [student] how do you think I can do work to this book? If I lift it right? So you got that server coming out of the kitchen and lifts that tray high over his head. Or when you guys are in the weight room and you're lifting weights. You're doing work because now which direction is my applied force still? Up? Ok. Now Frank [student] which direction am I moving it? Up. Ok, same direction. So now is work being done everybody? Yes. So that's the main thing you guys have to remember, that the force applied has to be parallel to where you're moving it.

This is then followed by a series of examples that Ms. Crawley goes over with the class. After the sample problems were successfully solved, Ms. Crawley introduced a laboratory exercise involving a spring scale to allow her students to visually understand the concept of work. Thus, for Ms. Crawley, her questioning of students provides her with the opportunity to not only gauge her students' current state of understanding but gives her the information needed to address their concerns so that she can respond appropriately.

Another important aspect of Ms. Crawley's teaching orientation is the frequent implementation of laboratory exercises to complement her daily lessons. During the observational period, such exercises became a recurring fixture in her class that students look forward to participating. Such hands on activities not only "spark students' interest in physics" but cemented the learning process for students because they were able to correlate and understand the mechanics and laws of physics independently.

According to Ms. Crawley, her adjustment and modification of her teaching orientation from her first year of teaching is not only attributed to her growth of the teacher knowledge base, but, more importantly, fundamental changes in her cognitive growth and belief structure about the nature of teaching. The "growing pains" she experienced during her initial years of teaching allowed her to consequently alter her teaching philosophy to make the subject of physics "more exciting and understandable" to her students.

Knowledge of Science Curricula

The two features of the teacher's knowledge of science curricula, goals and objectives and science curriculum, are associated and therefore shaped by Ms. Crawley's general orientation to teaching science. As a mid-career teacher who taught at the same district and school throughout her teaching career, Ms. Crawley has fully integrated her knowledge of the goals and objectives of physics into her daily lessons. For Ms. Crawley, this was accomplished through weekly staff meetings with other physics faculty members of the school so that their curriculum and lesson objectives are aligned with each other. Aside from knowing and following district mandates, Ms. Crawley's principal objective is to impart the scientific method to her students so that they can "themselves investigate" and determine "how things work." This belief structure, therefore, has shaped her present teaching orientation of having students actively participate in laboratory and field investigations.

Knowledge of Students' Understanding of Science

For Ms. Crawley, the knowledge of students' understanding of science remains the driving force behind her PCK growth. From her first year as a teacher, she has continually striven to improve her practice by implementing student driven activities to draw their interest in learning. Moreover, the impetus behind her belief in better relating the connection between student learning and teaching is the desire to understand her students. Her knowledge of students' understanding, therefore, is an ongoing endeavor that allows her to grow and develop her teacher knowledge base.

Ms. Crawley makes it her personal goal to know the learning inclinations of her students which allows her to fittingly respond through her discussions and activities. During her lesson on power, for example, Ms. Crawley was able to explain the meaning and relationship between work and power thereby establishing the support structure necessary for her students to quantitatively solve problems. Throughout the session, Ms. Crawley would lead and direct her questioning so that students were able to determine for themselves the procedures necessary to independently solve power problems.

> So we're going to talk about power. If I say a mustang is more powerful than my mini-copper, what does that mean? What does it mean when something is more powerful than something else? [class responds] More inertia, more energy, what else? Well let's look at the definition: if power is work over time [P=W/T], now rephrase that. Why is the mustang more powerful than my mini [car]? What does it have to be able to do? Ok. It can do the same amount of work in a shorter period

> of time. Right. Or it can do a lot more work in the same amount of time than my car can. And our unit for power is the watt. Where have you heard that term before? [George, student, responds] light bulbs. Ok so light bulbs are measured in watts. Ok what is the wattage of the light bulb? That is the amount of power dissipated by the electricity going through the light bulb. Ok so power is in watts. So it is the amount of work and how long it took you to do that. So let's do a comparison here: If I have two people in the weight room [Ben and Bonny] who are both lifting 50 kg of weight over their heads over a distance of 0.6 meters. Ben lifts the weight 10 times in 10 seconds and Bonny lifts the weight 10 times in 1 minute. So now talk with your neighbor and think about which student is doing more work and also who has the most power. What is the force being applied and what is the distance being moved? I want to hear talking now.

At this juncture, Ms. Crawley goes from one student group to the next examining their thought processes as they attempt to solve, mathematically, the problem entailing the relationship between work and power. But upon realizing that her students were encountering difficulties, Ms. Crawley responds:

> So let me lead you guys a little here. They're giving us 50 kg, what is that? What is kg the unit for? [Beth, a student, responds] Mass. Ok now we have to think back to our last unit. How do we change mass into a force? How do we change that 50 kg into an amount of force? Can someone help us remember how we change mass into weight? [Phil, a student responds] Mass times gravity. Right! Times gravity right. It's the gravitational pull that causing that force so you have to multiple your mass times gravity to get the force? Does that help you a little bit there?

Ms. Crawley then walks around the classroom examining if this scaffolding technique helps her students to get started. Still sensing that her students do not have a firm grasp of the problem, she intervenes by reminding the class about using the "GUESS" method in solving problems. GUESS, a mnemonic which stands for givens, unknown, equation, substitution, and solve, allows the students to attack and solve the problem in a step by step procedure that can be readily understood and remembered.

In addition, Ms. Crawley's tactic of addressing scientific misconceptions represents another facet of her knowledge of student understanding that has evolved during her tenure as a teacher. During the lesson on work and power, two common student misconceptions were detected and revolved by Ms. Crawley. First, during the discussion on work, some students did not fully comprehend how to identify the direction in which a force acts on an object. Ms. Crawley was only able to identify the misperception through her questioning, which was then resolved by the introduction and discussion of numerous examples with Ms. Crawley acting as a facilitator and director of student thought. The second misconception recognized and addressed by Ms. Crawley was the idea of mass and weight. During a discussion on problem solving power and work questions, Ms. Crawley, through her questioning, discovered students were assuming mass and weight to have the same connotation. As a result, they were having difficulty in setting up the work and, therefore, power equations that were necessary to solve the problem. Again, by way of discussing the need to know "physics' terms" along with a class discussion of several examples, Ms. Crawley was able to teach to the students the difference between the two terms.

For Ms. Crawley, her lessons culminate in a laboratory exercise that reinforces the topic that allows her students to actively participate and experience the mechanics involved in physics. During the lesson on power, for example, after Ms. Crawley was able to instill to her students the fundamental principles regarding work and power, a "stairs lab" was assigned where the students had to go up and down a staircase to calculate how much work and power was done during the exercise. In addition, during data collection, students were observed performing numerous activities (e.g. an egg drop experiment to demonstrate the laws of motion, a pulley laboratory exercise to help introduce the concept of work and energy, a roller coaster exercise to calculate energy types, and a free fall exercise to help students understand acceleration). Ms. Crawley states that such activities help students to “visually represent” what is learned in the classroom, which, in turn, is an acknowledgement of her continuous understanding of student thought.

Knowledge of Instructional Strategies

As an extension of the teacher’s orientation to teaching, the knowledge of instructional strategies acts as an avenue for teachers to express their teaching styles. This characterization correctly describes the purpose of Ms. Crawley’s use of strategies for her classes. As she became cognizant of the learning needs of her students, Ms. Crawley’s instructional strategies have changed accordingly. As a result, Ms. Crawley has resorted to having her students become actively involved in her lessons. Discussion of the lesson topics resembles a dialectical approach, with both teacher and student becoming active participants in coming to an understanding of the processes involved. However, unlike Mr. Branson, Ms. Crawley continues the discussion by providing demonstrations or assigning a laboratory assignment to reinforce the concepts discussed. This results in Ms. Crawley being able to discern her students’ train of thought so that she can respond appropriately. Therefore Ms. Crawley utilizes “lots of visual representations and demonstrations” to help the learning process.

Knowledge of Assessment of Scientific Literacy

The knowledge of assessment of scientific literacy, for Ms. Crawley, is part of the teacher knowledge base that allows her to gauge the effectiveness of her teaching. It allows Ms. Crawley to determine what additional interventions, if any, she needs to take to ensure the type of understanding she deems fit for her students. Assessments included in her repertoire include not only the traditional devices like homework and exams, but the responses she gets during her questioning of students during class discussions. In addition, student reactions and responses during assigned laboratory and field experiments are also used as an assessment tool to ascertain student understanding.

Ms. Dawson (Biology)

Entering her eighth year of teaching, Ms. Dawson teaches freshman biology at Hampshire High School (HHS). Her tenure at HHS began after receiving an undergraduate degree in biology and teaching certification from a local university teaching program. Ms. Dawson is also bilingual, as a result of spending time during her youth in Latin America, and teaches an ESL (English as a Second Language) biology course. In addition, she is a "floater" at HHS, a term used to describe teachers who do not have an established classroom (floating from one room to another). However, for Ms. Dawson, despite her years of experience, her overall PCK was observed to still be in the developmental stages of growth. Throughout the observational period, Ms. Dawson was observed to be reading from her PowerPoint presentations to her class with sporadic use of visual representations and analogies in her teaching. The two units observed in Ms. Dawson's class include lessons on animal systems and ecology.

Orientation to Teaching Science

Ms. Dawson's teaching reflects a teacher-centered orientation that is didactic based. Her daily lessons, resembling a direct instruction style of teaching, are scripted in the following fashion: a daily warm-up question for her students to start class followed by a lecture and note taking session. When questioned about her teaching orientation, she replied that she's "pretty much taught that way" and was "most comfortable" teaching in that fashion. Further probing her orientation to teaching revealed a connection to Ms. Dawson's time spent as a student and the influence of the "apprenticeship of observation" (Lortie, 1975) in her practice.

However, as an experienced biology teacher who has been teaching at HHS her entire career, Ms. Dawson has come to realize the need to adjust and fine tune her practice to suit her students. Even though the didactic teaching style conforms to Ms. Dawson's "comfort level," she recognizes that her method of teaching has room for improvement. "I know I can do a better job at it," she replies. Ms. Dawson comments further that she "wants to change" her teaching orientation to a have a more active approach to teaching but faced with time constraints in presenting the curriculum, she admits that such a change necessitates a time commitment she doesn't have.

Ms. Dawson's PCK growth as a result of her orientation to teaching is a direct response to her experience as a teacher. Her acknowledgement of her deficiencies in properly addressing her practice is the result of her experiencing the growing needs of her students as well as witnessing "other teachers teach" since being a "floater" has provided her with the opportunity to see firsthand other veteran teachers teach in order to determine aspects of their style that she could incorporate into her own practice. This willingness to adapt signifies the onset of PCK growth because it brings into play the process of cognitive change in the belief structure of Ms. Dawson's overall approach to teaching. Nevertheless, during data collection, no significant student-teacher interactions were observed that played a role in raising her teacher efficacy levels. Although Ms. Dawson, on her STEBI, indicated strong efficacious responses, classroom observations did not document any significant movement of teacher efficacy levels during classroom observations.

Knowledge of Science Curricula

Being an experienced teacher, who has been teaching at HHS for eight years, Ms. Dawson's knowledge of the science curriculum has been extensively developed. Her familiarity with both district and state mandates regarding the biology curriculum remains the focal point for developing and executing her lessons. This also extends to her knowledge of the goals and objectives for teaching biology. In addition, Ms. Dawson states that she regularly confers (three times a week) with her colleagues to establish lesson plans as well as to sync their teaching and learning objectives for the week.

Knowledge of Students' Understanding of Science

As an experienced science teacher, Ms. Dawson states that her knowledge of students' understanding has grown through the years and still continues to develop. One of the primary strengths of Ms. Dawson's PCK is her of level of understanding the needs of her students. Her amiable attitude has resulted in developing a fruitful relationship with her students. During the observational period, she was seen to be always willing to help and support her students, telling them to come to see her during her tutorial or lunch hours for assistance. However, issues of classroom management arose numerous times during classroom observations that question how she is able to properly develop her knowledge of student understanding.

Her approach and overall desire to help her students has enabled her to expand her knowledge base of better grasping students' understanding of science. As a result, Ms. Dawson growing teaching experience has allowed her to gradually develop her cognitive abilities to better differentiate student abilities and limitations in the classroom. Though her general teaching orientation has been the "traditional" method of lecture and note-taking, Ms. Dawson states she always "wants to do more with my kids" to make learning biology as tangible as possible. Observed examples in her class during data collection included the use of "visuals to have students see how things happen" during her lectures coupled with references to "real life experiences and analogies" pertaining to topics in biology to "help explain" biological phenomena. She further comments on her desire to "bring fun and excitement to biology" through a more pro-active approach to teaching but, as it was referenced to her teaching style, the time constraints and deadlines involved in teaching particular topics prevents her from using such tactics. “If I didn’t have to face departmental and district deadlines in teaching topics, I would love to use more inquiry based methods,” Ms. Dawson admits.

Knowledge of Instructional Strategies

As a result of her didactic teaching orientation, Ms. Dawson’s knowledge of instructional strategies incorporates direct instruction techniques in her daily lessons. The growth of her knowledge base has evolved, however, so that now she integrates the use of graphical representations, analogies, and questioning during her lecture in class. In addition, the participation of laboratory exercises, when it becomes mandated, also allows her to probe student thinking and levels of understanding.

Knowledge of Assessment of Scientific Literacy

The knowledge of assessment of scientific literacy for Ms. Dawson, as a consequence of her teaching orientation, was observed to be limited to the use and evaluation of student responses on worksheets, quizzes, district designed exams, and student notebooks. Student deficiencies exhibited on these assessments were addressed through student corrections which were then reevaluated by Ms. Dawson.

Research Question #2- *Does teacher efficacy among science teachers enhance the development of PCK? If so, how?*

The role of teacher efficacy in the development of pedagogical content knowledge (PCK) was examined with the three participating science teachers. Using data collected through classroom observations, teacher interviews, and responses from the Science Teaching Efficacy Belief Instrument (STEBI), the question of the effects of teacher efficacy in the development of the teacher knowledge base will be addressed. As mentioned in the methodology chapter, the STEBI was used, in conjunction with observations and reflective notes, as a filtering agent to isolate specific teacher efficacy episodes. Moreover, in light of the relationship between the development and growth of PCK and classroom experience, this research question, in effect, will be treated as a corollary to the first question. Therefore, this question has been organized by elements of the components of the model of PCK for science teaching.

Teacher efficacy is the "teachers' belief or conviction that they can influence how well students learn" (Guskey & Passaro, 1994, p. 628). The following illustrates how an efficacious teacher can have an appropriate teaching strategy that can respond to changes in the learning environment: On a lesson on simple harmonic motion to her AP Physics class, Ms. Crawley was introducing the concept of simple harmonic motion for the first time. During the brief introduction, Ms. Crawley, through her questioning, was not getting the appropriate response she was expecting. But because Ms. Crawley was confident in her abilities to address various student learning needs, she makes use of diagrams and representations to teach her lesson. This shift of teaching strategies coupled with a successful outcome in student learning further validated Ms. Crawley's teaching abilities which cascades into raising her teacher efficacy levels even further. "I know what to do," Ms. Crawley responds when asked about the appropriate use of a specific teaching strategy.

> So what simple harmonic motion means is anything that is repeated over and over, so it has periodic motion. Right? And so when you have a spring that is oscillating back and forth, that is exhibiting simple harmonic motion. Waves of an ocean exhibit simple harmonic motion, and our pendulum that goes back and forth and back and forth also exhibiting simple harmonic motion. Ok? And its related to its displacement. So we have a spring here [holding a spring model] and now what kind of energy are we going to and from? Student answers: Spring potential, elastic potential. Into what kind? Kinetic right? So April [student] which position A, B, or C will kinetic energy be the greatest? [no response from April] When its being stretched, compressed, or in its equilibrium point? [no response] So what kind of energy does stretching give? So is the stretch when the spring is in its equilibrium position? Bruce [student] what's the stretch when it's in the equilibrium position? [no response] Let me go grab my spring, maybe it will be easier to see in real life. [Using spring] right now it is the equilibrium position, stretched out. So at its equilibrium position is it stretched? No right so how much potential energy does it have? Ok. What's the equation that's relating these together? What's the equation for elastic potential energy? Right? What is mgh equal to? Gravitational right? Elastic is $1/2\ kx^2$ right? So the amount of potential energy that I have is directly related to what two things? Gravity and the spring constant? Right. With the same spring does K vary? No right, it stays the same so what's the only thing here that's different? The position right? At equilibrium what is the X? Zero right? So whats the gravitational potential energy there? Zero yes. So how do find kinetic energy? Yes so now where is our velocity going to be the greatest? A? B? or C? A right? Because there's where kinetic energy is greatest.

Throughout this exchange, Ms. Crawley's probing of student thought through her questioning techniques led her to discover that her students were not fully grasping the concept of the spring constant and its relationship to kinetic and potential energy. The first response was the introduction of a spring model to demonstrate the various stages of the spring constant. Towards the end of the exchange, Ms. Crawley was getting some correct responses to her queries but sensing the class was not understanding the material, more representations and a demonstration with various models were brought into the classroom. The outcome of this particular teaching episode was a successful one in which students abstractly comprehended the mechanism of simple harmonic motion by correctly solving several problems from Ms. Crawley.

> Let's look at one more thing because I think you guys are still confused. Right now my spring is at equilibrium? Yes so now let's put some mass here, I'm going to put a 50 g mass on here. So its oscillating back and forth. If I stretch this out where what kind of energy? Elastic potential energy right. What happens the more I stretch it out? More potential energy right? So what should happen when I release it? Faster right? So what kind of energy does it turn in to when I release it? Kinetic energy. And what is kinetic energy related to? Velocity right. So the more I stretch the faster it's going to go right?

Ms. Crawley's teacher efficacy in this particular lesson exemplifies how it can lead to growth in her knowledge of student understanding, a key facet of the model of PCK. By probing and asking specific questions during her lesson, Ms. Crawley gains a better understanding of her students' thinking process and their current knowledge state. Getting correct responses to her questions, allows Ms. Crawley's teacher efficacy levels to rise. Furthermore, due to her teaching experience, Ms. Crawley becomes better aware of deficiencies in her teaching approach, which she gauges with the type of responses she gets during her questioning.

For the three experienced science teachers who participated in this study, teacher efficacy served as a conduit for changing their beliefs towards teaching. However, Ms.

Dawson's low teacher efficacy levels have been observed to have the opposite effect from both Mr. Branson and Ms. Crawly. For Ms. Dawson, her low teacher efficacy has altered her beliefs towards teaching in a manner that has made her revert to the "traditional" style of teaching she has grown accustomed to. Even though she has over eight years of classroom teaching experience, Ms. Dawson's PCK, when compared to the other two teachers, was observed to be significantly less developed. This alteration and modification of their cognitive belief structure thereby acts as the medium for shifting and developing the teachers' knowledge of student understanding, which, in turn, influences and shapes their general orientation to teaching science. Therefore, teacher efficacy acts as an "affective affiliate" (Park, 2007) for PCK growth, which highlights its instrumental role in advancing the PCK of teachers.

Knowledge of Student Understanding of Science

For the three participating teachers (Mr. Branson, Ms. Crawley, and Ms. Dawson), teacher efficacy was observed to be the impetus behind the change in their beliefs towards teaching. This modification to the belief structure is the result of the teachers' personal need to improve their practice. "I want to do better," Ms. Crawley states regarding her teaching practice while Ms. Dawson admits that she "can do better because I know I can." Even though Ms. Crawley and Ms. Dawson both believe that they possess the capability to teach better, different teacher efficacy levels were observed with Ms. Dawson possessing much lower levels. The teachers' principles about their approach to teaching are a dynamic component that becomes precipitated by the interactions that take place in the classroom. Mr. Branson comments that it is the "result of student effort" that influences his teaching. During the observational period, the frequent questioning of students and the efforts students put into answering, was witnessed to not only ensure their understanding of the subject matter but was used to probe their critical thinking skills. It was such student effort that was the source of increasing the teacher efficacy levels of teachers. The following excerpt from Ms. Crawley's introducing her students to a "pre-lab" pulley exercise embodies such a situation:

> Teddy [student] what is the purpose of our lab that we're doing today? [student answers] Right! So we're looking at the relationship between pulleys, the number of pulleys we use and the amount of work that's being done. So what are going to be your predictions? As we increase the number of pulleys we have here lifting our load you do think there's going to be less force or more force to move it? Raise your hand if it's less? Raise your hand if it's more? [class hesitant and not sure] When people are working on engines in an auto shop, like when you go to get your oil changed, and they're working on your engine. Do they work on your engine while you're still in your car? [Class responds] No. No right you have to lift it right? How do they lift it? With a whole lot of pulleys right? So the more pulleys you have, the less force you have to apply to lift the same amount of weight. It's not the weight of the engine that's changing, but it gets easier because you use more pulleys. So we'll look at the relationship of how that changes during the lab.

The questioning coupled with the use of a real-life analogy to explain the pulley system brought out critical thinking skills necessary for Ms. Crawley's students to perform the assigned exercise. This instance not only confirms Ms. Crawley's teacher efficacy about her lesson but raises her efficacy levels since it validates her teaching strategy and knowledge of student understanding.

Thus, for teachers, the responses of their students to their queries become a vital source of reinforcing and raising their teacher efficacy levels. Moreover, this particular aspect encompasses the use of the teachers' knowledge of student understanding. For experienced science teachers, who have established a stable practice, their continued PCK growth can be attributed to their developing knowledge of students. And because teachers receive new students on a yearly basis, they need their knowledge of student understanding to stay current in order to meet the demands of teaching effectively. This is due to the fact that new students bring new challenges as well as new learning needs that teachers have to cope with. The primary stimulus for growth in the domain of the knowledge of student understanding for experienced science teachers therefore is the teacher efficacy of teachers. However, for Ms. Dawson, who represents a contrasting case, her rate of growth of the knowledge of student understanding is much lower than the other teachers due to the diminished role of teacher efficacy in her PCK development. Whereas Mr. Branson and Ms. Crawley both have classroom teaching experience and high teacher efficacy levels to sustain their PCK growth, Ms. Dawson only has classroom experience driving her PCK which does help in her growth but at a much lower rate than the other teachers.

This was the case for the participating teachers in this study, as they have reaffirmed their cognitive beliefs about their ability and conviction to understand the nature of student understanding. Examples found to support this claim lay in their treatment of student misconceptions in science, particularly Mr. Branson and Ms. Crawley. When confronting an abstract topic, such as the mole concept and oxidation-reduction reactions in chemistry or the conservation of energy in physics, both Mr. Branson and Ms. Crawley tackle student misunderstanding through the use of examples, mnemonics, and representations that they feel confident enough will work to resolve the issues with the students (refer to p. 94 for Mr. Branson's discussion on Avogadro's number). Additional misconceptions addressed by Mr. Branson include the concept behind oxidation-reduction reactions. The misconception held by Mr. Branson's students was not having phonemic awareness between an oxygen element to oxidation-reduction reactions. Mr. Branson's solution was a mnemonic to better define the parameters behind oxidation-reduction reactions (refer to p. 96 for Mr. Branson's discussion on mnemonics for oxidation-reduction reactions).

For Ms. Crawley, misconceptions were addressed by probing her students to critically think and convince themselves to approve and accept corrections. First, during the discussion on work, some students did not fully comprehend how to identify the direction in which a force acts on an object. Ms. Crawley was only able to identify the misperception through her questioning, which was then resolved by the introduction and discussion of numerous examples with Ms. Crawley acting as a facilitator and director of student thought. The second misconception recognized and addressed by Ms. Crawley was the idea of mass and weight. During a discussion on problem solving power and work questions, Ms. Crawley, through her questioning, discovered students were assuming mass and weight to have the same connotation. As a result, they were having difficulty in setting up the work and, therefore, power equations that were necessary to solve the problem. And again, by way of discussing the need to know "physics' terms" along with a class discussion of several examples, Ms. Crawley was able to teach to the students the difference between the two terms.

Therefore, the teachers, in essence, are prepared for such obstacles in their lessons and address them immediately due, in part, to their respective teacher efficacy towards understanding students.

Orientation to Teaching Science

For both Mr. Branson and Ms. Crawley, their experiences during their initial years of teaching have provided them with the knowledge base necessary to be successful. Both admitted that their "confidence levels" were low and waning during those years due to the lack of success in "connecting with students." Student responses and, more importantly, student interests in learning were lacking. For Ms. Crawley, she replied that such times served as a "wake up call" to change. "My approach to teaching was the usual lecture and note-taking that wasn't going anywhere," she admits. In Mr. Branson's case, the cosmopolitan makeup of his students during his first couple of years taught him to better connect with his students in order for him to learn their learning proclivities and structure his teaching accordingly. In both instances, Mr. Branson and Ms. Crawley, who were facing a daunting task of teaching for the first time, were efficacious enough to believe that they can do better. As a result, their teacher efficacy levels began to rise when they undertook their mission of becoming better educators. For Ms. Crawley, it was a complete alteration of her orientation to teaching to make students more active in her lessons while Mr. Branson undertook the approach of making his teaching more structured to accommodate his students. So for both Ms. Crawley and Mr. Branson the use of questioning and probing student thought became an indispensable tool that allows their teacher efficacy levels to increase.

Furthermore, due to the relationship between a teacher's orientation to teaching science and the knowledge of student understanding of science in developing and cementing the teacher's PCK, teacher efficacy plays a vital role in shaping the belief system of teachers. As a result, teachers undergo a process of self-evaluation that mirrors the process of social cognitive change in which "cognitive events (become) induced and altered by experience of mastery arising from effective performance" (Bandura, 1977, p. 191).

This observation reaffirms the role of teacher efficacy in the development of PCK. In Ms. Dawson's case, because she lacks teacher efficacy, her PCK levels are lower. For experienced science teachers, their sense of teacher efficacy becomes dependent on a successful interaction with their students, which allows them to learn their learning strengths and weaknesses. This virtuous feedback cycle of action and reaction to their daily lessons strengthens their belief structure thereby developing their individual knowledge of student understanding which then causes growth in their PCK. This progression continues due to the introduction of new students every year.

Contrasting Case of Teacher Efficacy

Unlike the other participating teachers, Ms. Dawson was observed to have low teacher efficacy levels. Although Ms. Dawson consistently scored high on the STEBI, classroom observations indicated otherwise. This disparity can be attributed to the differences between self-efficacy and teacher efficacy. Bandura (1977) states that two modes of operation exist in efficacy: efficacy expectations and outcome expectations. While efficacy expectations deal with an "individual's beliefs about his or her own capability to achieve a certain level of performance," (Guskey & Passaro, 1994, p. 629) outcome expectations are the "individual's estimate of the likely consequences of performing that task at the expected level of competence" (Tschannen-Moran et al., 1998, p. 210). Examples of such consequences that were observed in this study include student motivation and interest as well as student performance on science topics.

This distinction separates self-efficacy from teacher efficacy because self-efficacy involves the teacher's perceptions that he/she can do better in a particular situation or context while teacher efficacy encompasses the enactment of his/her behavior according to the teacher's beliefs. The answers on the STEBI, therefore, reflect Ms. Dawson's perceived self-efficacy levels while her actual behavior in the classroom captured her teaching efficacy.

So even though Ms. Dawson, as indicated by her STEBI, possessed high self-efficacy, indicating that she believed she had the skills and capability to carry out her teaching duties, data from classroom observations indicated that her actual teaching efficacy was low and not developed. As a result of having low teacher efficacy, Ms. Dawson's level of PCK growth, when compared to both Mr. Branson and Ms. Crawley, was observed to be significantly lower. Classroom discussions that bring out critical thinking skills and questions were absent during her lessons, unlike the other teachers.

The following example, which covers an activity dealing with population growth, illustrates Ms. Dawson's low teacher efficacy even though her self-efficacy was high:

> We're going to be discussing carrying capacity today. When we reach the maximum population that can be supported by the ecosystem, we've reached that carrying capacity. So carrying capacity is when there's some stability in the population and if there's something that changes it, oh I don't know, a natural disaster, disease, or changes in climate, those things can change the carry capacity. So let's start out by looking at what you are going to be doing in this activity today. So your group is going to get a bunch of index cards. Ok. Each card represents one lily pad. It tells us on here that [reading from handout] you're going to lay down one which represents your first lily pad and when one day passes you're going to double your lily pads and you're going to record that in your data table. So on the first day you're going to have one lily pad and your total will be one. And when they reproduce you're going to double your lily pads. So on day two it will be two and day three four. So you're going to write down how many gets reproduced and then you're going graph it. Then on the next page [referring to handout] there are a few questions and some background information that explains how growth rate happens, what exponential growth is. You need to read that, you need to understand it. So I'm going to have you guys work at the lab tables and you're going to start your lily pad assignment. Are we good?

For Ms. Dawson, her responses for the lily pad activity on the STEBI were indicative of someone having a firm and positive conviction of her skills as a science teacher. Her self-efficacy levels were high because she strongly agreed to knowing the "steps necessary to teach science concepts effectively" (question 4) while strongly disagreeing to the question (6) on whether she was "not very effective in monitoring science experiments." For the lily pad activity described, as soon as she gave out the assigned activity to be carried out, Ms. Dawson was observed sitting on a separate table grading worksheets. Students were, for the most part, left to do the activity themselves without any guidance from Ms. Dawson and if students had questions, they were referred to the handout that came with the activity. Teacher efficacy, in this particular episode, was lacking due to Ms. Dawson not engaging with her students during the activity resulting in sparse questioning and no monitoring of her students. Observational notes made during the activity indicated that Ms. Dawson did not seem comfortable about the concepts of population biology since topics about carrying capacity, exponential growth, and limiting factors were not clearly defined to her students. Instead, Ms. Dawson would simply refer students to the handouts given to understand the terms.

Therefore, Ms. Dawson's contrasting case provides additional information about the nature of efficacy to PCK growth that was missing from the other participating teachers, particularly the role of self-efficacy. For PCK to develop and be sustained, it is teacher efficacy that becomes the engine for its growth since it involves the consequences of acting as opposed to having thoughts about it. The following table shows how PCK growth and efficacy were observed for the participating teachers and their relationship with other.

Table 1

Efficacy and PCK among Participating Teachers

	Evidence of Teacher Efficacy	Evidence of Self-Efficacy (STEBI Results)	Evidence of PCK Growth
Mr. Branson	High teacher efficacy levels: increased student interest and motivation (through successful questioning)	yes	Increased knowledge of student understanding: adapting teaching style and approach to know student learning needs on scientific concepts
Ms. Crawley	High teacher efficacy levels: increased student interest and motivation (through successful questioning)	yes	Increased knowledge of student understanding: adapting teaching style and approach to know student learning needs on scientific concepts
Ms. Dawson	Low teacher efficacy levels: lack of student interest and motivation due to not questioning students successfully (no critical thinking questions)	yes	none

CHAPTER 5: DISCUSSION AND CONCLUSIONS

Introduction

A detailed analysis of the results pertaining to the research questions are presented in this chapter. The development and subsequent role of the teacher knowledge base is a critical feature of teaching that warrants a closer examination delineating the conditions required for its growth among teachers. Qualitative data collected for this case study helped reveal such conditions in the continued growth and development of pedagogical content knowledge (PCK) among experienced science teachers as well as defining the role of teacher efficacy in cementing such knowledge acquisition. The data indicates that, for experienced science teachers, the growth of teachers' PCK is mainly attributed to their knowledge of student understanding with teacher efficacy becoming the primary impetus for their deepening understanding of student learning. This results from the positive interactions that take place with teacher and student during a lesson that reinforces the teacher's desire to learn more about his/her students' thought processes and understanding of the subject matter.

However, for Ms. Dawson, who has been observed to have lower teacher efficacy than the other two participating teachers, her rate of PCK growth diminishes. Ms. Dawson's sole driving force for her PCK is her classroom teaching experience. This observation reaffirms Park's (2007) concept of outlining teacher efficacy as being an "affective affiliate" of PCK development. Moreover, this consequence also necessitates a reevaluation of Magnusson et al.'s (1999) model of PCK for science teachers to include teacher efficacy as being an integral component of the teacher's PCK.

Research Questions

1. Does PCK evolve over time among experienced science teachers? If so, how? And how does classroom experience contribute to PCK development?
2. Does teacher efficacy among science teachers enhance the development of PCK? If so, how?

Summary of the Study

This collective case study investigated the developing and sustaining nature of pedagogical content knowledge (PCK) among experienced science teachers. The concept of teacher efficacy was studied to determine its stimulative effect on the continued growth progression of the teacher knowledge base. In addition, Ms. Dawson's contrasting case demonstrated how low teacher efficacy stalls PCK growth and development. This is due to the diminished role of teacher efficacy driving her development even though her self-efficacy levels remained high.

The analysis of the qualitative data collected revealed a deeper understanding of the developmental pathway of PCK and the role of teacher efficacy in buttressing its growth among experienced science teachers. The results supported the supposition that teaching experience is a necessary and paramount feature of PCK development. As science teachers gain classroom teaching experience, their knowledge of student understanding undergoes a period of growth due to the teachers becoming better aware of their learning needs through classroom interactions that take place during instruction. The result of increasing their knowledge base of student understanding allows the teachers' PCK to continually develop since the knowledge of student understanding is a key facet of PCK.

Furthermore, results of the data also established the casual role of teacher efficacy in PCK development as it served as the primary catalyst for teachers to cultivate their knowledge of student understanding. This was observed as a virtuous cycle whereby teacher efficacy that teachers receive as students are able to successfully answer and solve problems posed to them increases the teachers' desire to learn more about their students' knowledge of understanding. This feedback loop, therefore, involves teacher efficacy influencing the growth of the knowledge of student understanding, a key facet of PCK.

Discussion

Shulman (1987) characterizes teaching as being a "learned profession" (p. 9) that requires teachers to possess "complex bodies of knowledge and skill needed to function effectively" (p. 4) in the classroom. This collective knowledge base of teaching, therefore, is a significant and integral aspect of teaching that merits further examination. As a result, the purpose of this case study was to delve into better understanding the developmental process of pedagogical content knowledge (PCK) and the requisite conditions required for its growth. Findings revealed the role of classroom experience and teacher efficacy playing a critical role in developing and sustaining PCK growth through the growth of the teachers' knowledge of student understanding.

Changes in Teacher's Cognitive Belief Structure

The fundamental basis for the development of PCK lies in the sociocultural model of learning which places "social interaction among and between people as a primary source of knowledge" (Howe & Stubbs, 1997, p. 171). Since teaching is an activity driven venture built on social interactions, teachers are in a constant state of adjusting and reinforcing their beliefs in response to experiences they encounter in the classroom. Dewey (1916) argues that "experience as trying involves change, but change is meaningless transition unless it is consciously connected with the return wave of consequences which flow from it" (p. 139). Thus, for teachers, the process of learning and then cultivating knowledge as they gain classroom teaching experience is accomplished through the actions and reactions that occur on a daily basis between teacher and student.

Positive experiences reinforce the teacher's established belief structure. Negative experiences, on the other hand, causes the teacher to undergo a reevaluation of his/her actions and beliefs that mirrors Cochran et al.'s (1993) "knowing in action" model of understanding, which is based on shaping teachers' beliefs through an active process of reflection. This description aptly applies to Ms. Dawson's situation since her teacher efficacy was observed to be low. Furthermore, since self-efficacy, which was high for Ms. Dawson, does not entail the consequences of enacting behavior, it does not become a factor in the growth of PCK as opposed to teacher efficacy, which entails carrying out behavior according to their beliefs and awareness of the situation. For Ms. Dawson, her low teacher efficacy resulted in teaching in a didactic manner reminiscent of the traditional style of teaching she grew up with as a student, through an "apprenticeship of observation" (Lortie, 1975).

This transformation of the cognitive belief structure of teachers, therefore, influences their epistemological views in response to their desire to change and improve their practice. For both Mr. Branson and Ms. Crawley, their exposure to circumstances they experienced in the classroom has enabled their belief structures to have the plasticity needed to adapt and change their approach. On the other hand, with Ms. Dawson, her belief structures remained inflexible even though she wanted to change because of the negative consequences she encountered on incidences where she attempted to change.

As a result of their experiences during their induction teaching years, Mr. Branson and Ms. Crawley have both adjusted their teaching style in response to their interactions with students. Lemke (1990) writes that a "lesson is a social activity (and) a human social construction" (p. 2). Thus, for Ms. Crawley, who had begun her career strictly with a didactic teaching style that emphasized learning through a lecture and note-taking approach, she began to realize the limitations and scope of her practice due to her interactions with her students at that time. She perceived a lack of interest and motivation among her students which resulted in a change in her cognitive belief structure to seek out a new way to teach. "I was boring," Ms. Crawley stated about her didactic approach. This initiated a chain reaction of rethinking and reformulating in Ms.

Crawley's cognitive beliefs about the best avenue to confront and resolve her situation. The result was a distinct change in her orientation to teaching science from a didactic approach to an activity-driven style that was more student-centric.

Mr. Branson's experience resulted in a similar change in his beliefs about teaching and learning. His exposure to a diverse group of students during his initial years made him more aware of student differences and learning styles. As a result, Mr. Branson, like Ms. Crawley, had to reevaluate his belief structure about students and learning and adapted his teaching style accordingly. The practice of successful teaching is thus grounded on the model that teachers possess the capacity to evolve their belief structure to cope and deal with the interactive nature of the classroom. This is accomplished by the notion that a teacher's "cognitive and other behaviors are guided by and make sense in relation to a personally held system of beliefs, values, and principles" (Clark & Peterson, 1988, p. 287). For Ms. Dawson, however, this has become a hindrance to her development as a teacher since she was observed to have an inflexible belief structure as a result of having low teacher efficacy. In order to fully develop and grow, teachers must be willing to reflect and evaluate their practices in order to validate or reexamine their attitudes and beliefs about teaching and learning which helps in strengthening teacher efficacy.

As teachers continue to gain traction in the classroom, the values and beliefs they hold gets adjusted and promulgated through the interactions and responses they receive from their students. So the notion of certain aspects of classroom teaching experience, such as teacher efficacy, having a critical role in changing the teacher knowledge base, particularly PCK, becomes an important factor in better understanding its development. With this concept, teachers are continually growing and adapting their practice according to their belief structures. Therefore, changes in teaching style that were documented by both Mr. Branson and Ms. Crawley become an ongoing process that encompasses their knowledge of student understanding as their time in the classroom increases while no significant changes, in Ms. Dawson's case, hindered development.

After establishing a codified set of beliefs in response to their successful teaching experience, Mr. Branson and Ms. Crawley continue to test their established belief systems through their students. This aspect becomes the driving force behind the growth of PCK among experienced teachers. Having learned to adjust their teaching style, both teachers' growth comes from their awareness of the knowledge of student understanding. They become cognizant of student misconceptions and individual learning styles as new students come into their classrooms every year. As experienced science teachers, both Mr. Branson and Ms. Crawley begin to learn more about their students as the school year progresses resulting in the growth of their teacher knowledge base.

Expanding on the work of Piaget's (1974) theory of conceptual change, Posner et al. (1982) posit the existence of two phases of conceptual change, assimilation and accommodation, responsible for changing the belief structures of teachers. Assimilation, a process that describes how individuals "use existing concepts to deal with new phenomena," and accommodation, when individuals' "current concepts are inadequate to allow [them] to grasp some new phenomenon successfully [individuals] must replace or reorganize [their] central concepts," (p.212) are the routes teachers take as they begin to develop their teacher knowledge base. For Mr. Branson and Ms. Crawley, their cognitive development and subsequent change in their teaching orientation began with the process of accommodation since their teaching beliefs, at the time, became unsuited to meet the learning challenges they encountered with their students. But as they both became acclimated to their respective classrooms, the teachers beliefs became malleable to change and adapted to circumstances that arose. Their cognitive state then transforms into an accommodation mode allowing the teachers to further develop their PCK by incorporating their new set of beliefs to help mold and grow their knowledge further. Ms. Dawson, on the other hand, undergoes the process of accommodation but has not been fully committed since her central concepts on teaching have not been behaviorally enacted.

PCK Development

Elucidating the developmental pathway of PCK and the role of teacher efficacy in its sustained growth among experienced science teachers were the primary objectives for this study. By employing the Magnusson et al. (1999) model of PCK for science teaching as a theoretical framework for this study, data analysis disclosed how PCK evolves over time for experienced teachers and that teacher efficacy plays a prominent role in its progression. Grossman (1990) posits four possible avenues for PCK to develop: (1) apprentice of observation, (2) disciplinary background, (3) professional coursework, and (4) learning from experience. For the participating teachers in this study, their PCK during their initial years of teaching was molded through a combination of their educational experience (teacher certification and college courses) and apprentice of observation. But as the teachers begin to accumulate classroom experience, their PCK develops and continues to grow as their teaching experience increases.

This approximate chronological sequence of PCK development mirrors how the participating teachers' PCK evolved over time. Without any formal classroom experience, the teachers' only real connections to PCK were the educational classes they took in preparation for their teaching certification and their memories of classroom teaching while they were students. This latter connection, which Lortie (1975) coined as the "apprenticeship of observation," is an influential and dominant factor in shaping the PCK of teachers entering the profession for the first time. The primary reason for this basis lies in the belief structure of beginning teachers alignment of what constitutes effective teaching. Without a firm comparison to examine and evaluate their teaching methods, the participating teachers' induction years were a period full of what Ms. Crawley described as "growing pains." The teachers, initially, reflected on their years as students and attempted to mimic what they believed to be good teaching. Because this was reinforced through their personal belief structure, the participating teachers all took this particular route.

But as the teachers began to gain classroom teaching experience, as mentioned in the previous section, a shift in their cognitive belief structure occurred that provided the impetus needed to change their teaching approach. This shift is the result of student feedback and learning outcomes that did not aligned with previous beliefs that the teachers held. Therefore, a fundamental aspect of PCK development lies not only in culminating classroom experience but in convincing teachers to be adaptable and dynamic in their teaching approach. Green (1971) writes that if “beliefs are held on the basis of evidence or reasons, they can be rationally criticized and therefore can be modified in the light of further evidence or better reasons” (p. 48). The data collected for this study supports this supposition since student feedback and classroom performance induced cognitive changes to occur in the teachers to seek out new teaching strategies that would have a lasting impact on their students.

Closer examination of the qualitative data revealed that as science teachers gain experience their primary conduit for further developing PCK is through knowledge gained about students and their learning and understanding of the subject matter. Grossman (1990) states that the collective knowledge base of teachers is comprised of four distinct components: PCK, subject matter knowledge, knowledge of context, and general pedagogical knowledge.

For the participating teachers in this study, observational and interview data support the theory that, for experienced teachers, their PCK growth is manifested in their collective knowledge of students. Subject matter knowledge (SMK) and general pedagogical knowledge were observed to have little impact in sustaining PCK growth among experienced teachers due to the teachers’ mastery of content matter and pedagogical knowledge early in their teaching careers. So unlike beginning teachers, whose PCK growth would include developing in all facets of the teacher knowledge base, experienced teachers’ PCK growth is concentrated on honing their knowledge about their students.

Therefore, the knowledge of student understanding, a key component of the model of PCK for science teaching (Magnusson et al., 1999), becomes a critical aspect responsible for bolstering and strengthening PCK as teachers gain classroom teaching experience. The knowledge of student understanding "refers to the knowledge teachers must have about students in order to help them develop specific scientific knowledge" (p. 104). For Mr. Branson and Ms. Crawley, who are both actively developing their PCK, their knowledge of student understanding becomes a dynamic aspect of their teaching repertoire. During the observational period of the study, a common denominator of the participating teachers was the constant presence of questioning their students. Through their questioning, the teachers were able to deduce student reasoning on scientific concepts and skills during the lesson. In addition, such question and answering sessions enables the teacher to address common scientific misconceptions students have as well as providing the opportunity for the teacher to learn more about the learning styles of students.

According to the model of PCK for science teaching (Magnusson et al., 1999), the teacher's orientations toward teaching science, which encompasses the "teachers' knowledge and beliefs about the purpose and goals for teaching science," is a pertinent facet of PCK that "serve as a 'conceptual map' that guides instructional decisions" (p. 97). As such, the teaching orientation of teachers become the focal point of their PCK due to its influence on the other components of PCK (knowledge of science curricula, knowledge of assessment of scientific literacy, knowledge of instructional strategies, and the knowledge of student understanding of science).

The influential relationship among the various facets of the PCK model to the teacher's orientation to teaching science becomes an important factor in better understanding the conditions of PCK growth among experienced teachers. By committing to a specific teaching orientation, teachers have established a cognitive belief structure that reinforces their position about furthering their knowledge base of the other components of the PCK model. Ms. Crawley, for example, exhibited an activity-driven teaching style that emphasizes a "hands on" approach to teaching. Her teaching approach, therefore, involves active student input and participation so her students become capable of scientific reasoning to tackle and solve problems posed to them. This approach also has serves as a guide for Ms. Crawley to delve deeper into understanding how the "hands on" approach to learning affects her knowledge of student understanding. Questioning how her students would react and respond to an activity driven venture allows Ms. Crawley to expand her knowledge base of student understanding that prepares her for future lessons. Examples observed include using different representations and laboratory exercises appropriate for different students resulting in Ms. Crawley to have a firmer grasp of different learning styles which, in turn, raises her awareness of the knowledge of student understanding.

Teacher Efficacy

Bridging together the theories of social learning and social cognition (Bandura, 1977; Rotter, 1966), teacher efficacy becomes a critical facet of PCK development. Defined as a "future-oriented belief about the level of competence a person expects he or she will display in a given situation" (Tschannen-Moran et al., 1998, p. 207-208), teacher efficacy plays a prominent role in cementing the teacher's orientation to teaching as well as the underlying knowledge of student understanding. The process of changing and adapting a particular teaching orientation was observed to be result of teacher efficacy levels of both Mr. Branson and Ms. Crawley. For both teachers, the incentive for changing their overall teaching approach was directly related to their individual efficacy levels in response to the actions and reactions of their students. Both experienced low teacher efficacy levels during their induction years because they perceived their students were not learning up to their expectations. This set in motion a chain of events that eventually led them to either alter or modify their teaching orientation to improve student learning and motivation in their classrooms. The initial step involved in this process of transformation is for the teacher to recognize their teacher efficacy and to respond by altering their belief structures. Only by establishing a new set of beliefs in response to their teacher efficacy levels can teachers actively take part in changing their perceptions about what is right or wrong about their approach. For example, in Ms. Crawley's situation, her change in teaching orientation from a didactic to an activity-driven venture was due to her teacher efficacy and reformulating her beliefs about student learning.

Furthermore, the relationship between teacher efficacy and the dynamic belief structure of teachers becomes a requisite condition for change and growth of the teacher knowledge base. Having high teacher efficacy levels causes the teacher to reinforce their belief structure while low teacher efficacy causes the teacher to reevaluate their belief system opening up the opportunity for teachers to change. This cohabitation and cooperative role of teacher efficacy and teacher beliefs, therefore, becomes the vehicle for which PCK becomes a sustained venture for experienced science teachers. Observations of the teachers questioning and discussing aspects of the lesson validated this assumption since such teacher-student interactions strengthens the resolve of the teacher's goal of teaching. In addition, teacher efficacy not only fortifies the teachers' beliefs about teaching, it assists in the development of the teachers' knowledge of student understanding.

Moreover, the role of teacher efficacy and self-efficacy, as it relates to the growth of PCK, needs to be clarified due to the differences between the two. The key dissimilarity between teacher efficacy and self-efficacy is the process of enacting behavior. An individual who merely believes that he/she is a good driver, for example, is different from one who believes he/she is a good driver and actually drives well. This analogy applies to the participating teachers since, in Ms. Dawson's case, her perceived self-efficacy was high (she believed in herself that she is a good teacher), but when she teaches, the subsequent negative consequences (i.e. student reactions and comprehension) of her actions would cause Ms. Dawson to revert back to actions she is most comfortable with even though she was aware. Having an awareness of wanting to do better is, therefore, different than having that awareness and actually performing actions to realize its presence. This was the case for Ms. Dawson and the other teachers. Both Ms. Dawson and Ms. Crawley were aware, for instance, of their inadequacies but it was Ms. Crawley who implemented behavioral changes to her practice while Ms. Dawson resisted and reverted back to her default teaching style (apprenticeship of observation) in her enactment.

The qualitative data therefore shows the process of how teacher efficacy affects growth of PCK. As a result, the data confirms what Park (2007) concluded about the role of teacher efficacy, that it is an "affective affiliate" of PCK due to its generative nature of fomenting knowledge development among teachers. The theory of teacher efficacy is based on competences that can "provide incentives and disincentives for a given behavior" (Tschannen-Moran et al., 1998, p. 210) which help situate the belief system of teachers. Examples of competences include recognitions and criticisms on matters of student motivation and performance. Therefore teacher efficacy becomes an essential construct for the growth of knowledge for teachers since it acts as a "promoter of a teacher's movement from understanding to action and vice versa" (Park, 2007, p. 780).

Teacher Efficacy Model of PCK Development

After finding a causal relationship between teacher efficacy and PCK development among experienced teachers, a modified developmental model of PCK needs to be formulized to account for the role of teacher efficacy. The data also supports Park's (2007) theory of teacher efficacy being an "affective affiliate" of PCK since it plays a "critical role in defining problems and determining teaching strategies to solve the problems, therefore leading to the reorganization of knowledge" (p. 780).

In the model of PCK for science teaching (Magnusson et al., 1999), the knowledge components are interconnected and influenced by the teacher's orientation to teaching science. So PCK's principal component, which was verified through this qualitative study, was the teaching orientation which dictates how the teacher becomes knowledgeable about the other four facets of the model. The model, however, does not provide parameters that influence or shape the orientation to teaching science, which is the role played by teacher efficacy.

As a result, a new model of understanding PCK needs to be established to include teacher efficacy as a driving force for growth and development. The study of teacher efficacy is a novel and new way of better understanding the nature of PCK which therefore warrants a place in PCK models of development. The proposed model (Figure 16) modifies and extends Magnusson et al.'s (1999) model of PCK for science teaching by incorporating a teacher efficacy component on top of PCK to signify its relevance in the development of PCK. Positioning teacher efficacy at the top of the diagram indicating its influence on PCK development corresponds to the data that was collected for this study. While both Mr. Branson and Ms. Crawley were able to express high levels of teacher efficacy, which led to their continued development of PCK, the opposite was true for Ms. Dawson. In her case, low teacher efficacy levels brought about a slower rate of PCK development even though she has been teaching for eight years. This fits the proposed model's role of placing teacher efficacy as having a direct influence on PCK development.

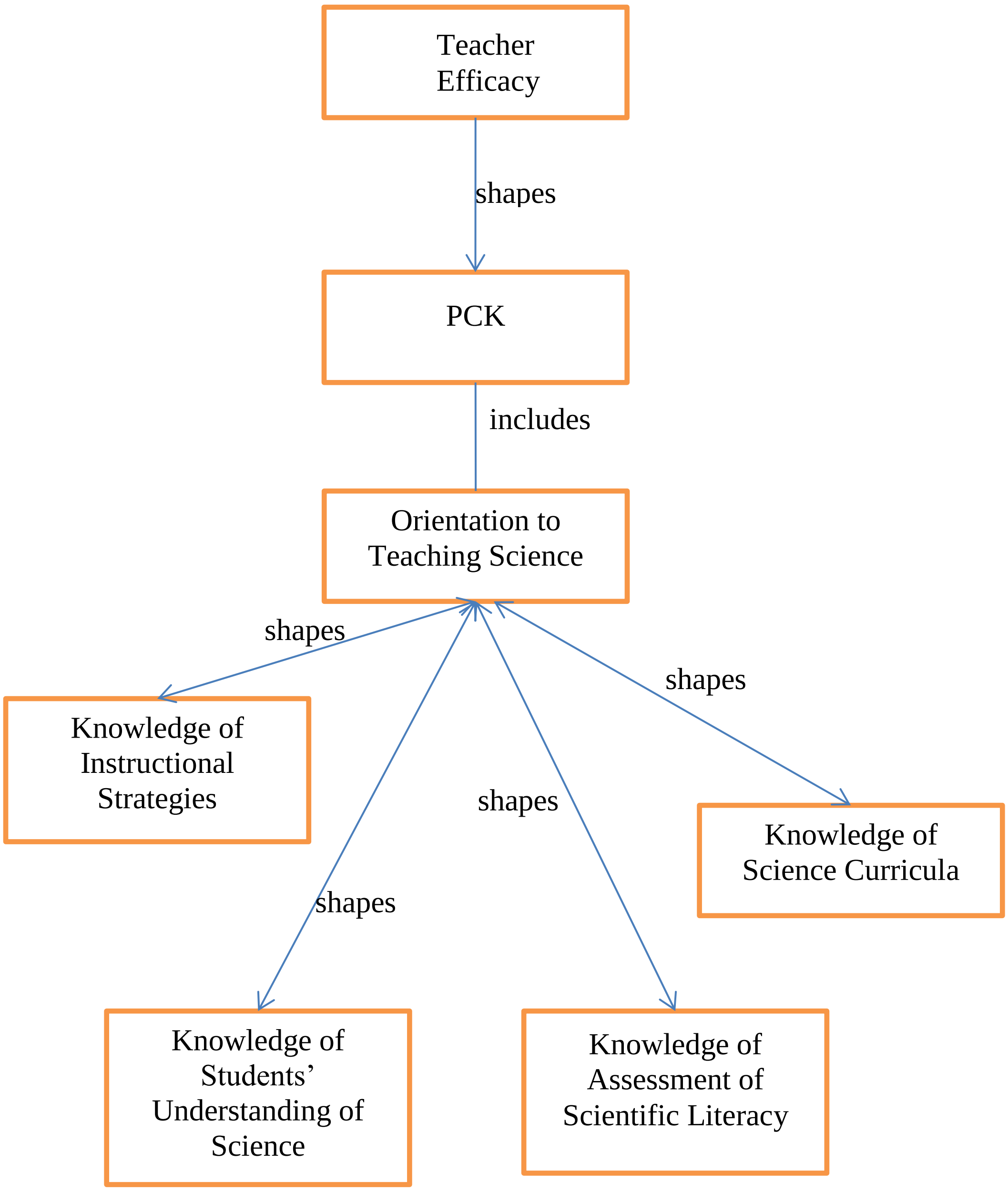


Figure 16. Proposed model of PCK for science teaching that includes the role of teacher efficacy. Adapted from *Examining Pedagogical Content Knowledge* (p. 99) by J. Gess-Newsome and N.G. Lederman (Eds.), 1999, Dordrecht: Kluwer. Copyright 1999 by Kluwer Academic Press. Adapted with permission.

Recommendations and Implications

Teaching is a critical endeavor that bridges the learning divide between student and teacher. Encompassing more than the transmission of knowledge, teaching is an active social activity (Lemke, 1990) that entails teachers having the necessary knowledge and skills to understand and interpret student learning. Therefore, pedagogical content knowledge (PCK), defined as the "capacity of a teacher to transform the content knowledge he or she possess into forms that are pedagogically powerful and yet adaptive to the variations in ability and background presented by the students" (Shulman, 1987, p. 13), becomes a requisite knowledge base for effective teaching.

Because of PCK's relevance in influencing the development of a sound and effective teaching practice, this study sought to better understand the developmental process of PCK growth among experienced science teachers. Having a fuller and deeper understanding of the developmental process of PCK would assist pre-service and in-service teachers as they get acclimated to classroom teaching. The results showed that the overall basis and engine for teacher knowledge growth lies in better comprehending the shifts and adjustments made in the teacher's cognitive belief systems. Successful or unsuccessful student-teacher episodes help validate or reevaluate the teacher's beliefs about learning. Such interactions help shape teacher efficacy levels which, in turn, serve as a vehicle for the development of PCK. Moreover, by presenting teachers positive opportunities to evaluate and validate their beliefs about teaching and learning, effective teacher education programs can be structured to allow teachers' PCK to mature.

Central to the cognitive belief structure is its malleability to adapt because when "beliefs are held on the basis of evidence or reasons, they can be rationally criticized and therefore can be modified in the light of further evidence or better response" (Green, 1971, p. 48). So seeking out aspects of the classroom teaching experience responsible for developing PCK was the focus of this study. Results showed that as teachers become accustomed to their teaching practices, their knowledge of student understanding continues to develop due to their high teacher efficacy levels on their teaching abilities. Because teachers continue to have a new group of students every year, their knowledge of student understanding becomes the driving force in their sustained growth of PCK. Central to understanding the progression of PCK growth was to seek out ways to change the belief structure of teachers through real-life representations that can rationalize their decision to adjust. Thus a properly structured professional development program that focuses on successful learning interactions that increases student motivation and performance during field training could be sanctioned as a first step towards formulating an effective and progressive program.

Since field training is a critical and necessary component in any teacher education programs, its use becomes instrumental in forging effective teachers. The social interactions that take place in the classroom between teacher and student are the opportunities teachers need to evaluate their teaching belief system. Such interactions can either reaffirm or review the teachers approach to student learning. It is this aspect of teacher learning that becomes important when designing and implementing professional development programs.

Limitations

The primary limitation encountered during this study dealt with contextual issues that are prevalent in qualitative studies. Teachers are individuals with separate and distinct cognitive belief structures that influence their practice. To settle some contextual issues that deal with investigating teacher knowledge, two classes for each participating teachers were observed. In addition, all of the participating teachers have been teaching for at least eight years (with two teachers having spent their entire career at Hampshire High School) at the same school. Even with these variables addressed, the individualities of the teachers cannot be ignored. The purpose of a case study is to present a generalized overview of the phenomena of teacher knowledge growth. To that end, this study was successful in capturing significant moments of teaching that drive and do not drive PCK growth among teachers.

Another limitation that was confronted during the study dealt with an issue of categorization. Results of the study determined that the knowledge of student understanding, according to the model of PCK (Magnusson et al., 1999), was the driving force behind PCK development. However, data analysis revealed a similarity of data that can be categorized into either the knowledge of context of students, which Grossman (199) defines as the "knowledge of specific students and communities, and the students' backgrounds, families, particular strengths, weaknesses, and interests" (p. 9), or the category of the knowledge of student understanding of science, which "refers to the knowledge teachers must have about students in order to help them develop specific scientific knowledge" (Magnusson et al., p. 104). Overlaps between the two were a frequent occurrence during data collection and the decision to categorize it under the knowledge of student understanding of science was made due to its presence during lessons.

A possible explanation might involve the use of both types of student learning in a sequence of events that leads to PCK growth. In other words, the knowledge of context would occur first so the teacher gets familiar with the student, which would then lead to developing the teacher's knowledge of student understanding. This organization suggests that the knowledge of context could serve as a foundation from which learning the knowledge of student understanding can be achieved.

Further Research and Questions

In order to fully comprehend the developmental and growth process of the teacher knowledge base, further studies on PCK need to be conducted to broaden the scope of understanding its evolution among teachers. Analysis of the data revealed the contribution and influence classroom teaching experience has on the development of PCK. Since teacher efficacy and the cognitive belief system of teachers were observed to play a prominent role in PCK growth, further studies that can investigate the mechanism behind the relationship between shifting belief structures and teacher development would provide a better lens to help understand the process better. Understanding the cognitive traits responsible for developing a sound and effective practice would help delineate the learning process teachers undertake once they enter the classroom. Contextual factors that contribute to teacher development also needs to be investigated since they help shape the teacher's attitudes and personal beliefs about teaching.

Additionally, follow-up longitudinal studies that focus on the development of PCK as teachers gain teaching experience would be helpful in verifying the modified model of PCK for science teaching that was introduced in this study. Documenting and determining pertinent factors and events that help influence teachers' practices in a longitudinal study can be very useful in better understanding the complexities of PCK development since it could help clarify and overcome the limiting factor encountered with teachers' self-reports on their teaching experiences.

APPENDICES

APPENDIX A: CoRe PCK INSTRUMENT TEMPLATE

Year Level for which this CoRe is designed.	IMPORTANT SCIENCE IDEAS/CONCEPTS								
	BIG IDEA "A"	BIG IDEA "B"	BIG IDEA "C"	BIG IDEA "D"	BIG IDEA "E"	BIG IDEA "F"	BIG IDEA "G"	BIG IDEA "H"	BIG IDEA "I"
What you intend the students to learn about this idea.									
Why it is important for students to know this.									
What else you know about this idea (that you do not intend students to know yet).									
Difficulties/ limitations connected with teaching this idea.									
Knowledge about students' thinking which influences your teaching of this idea.									
Other factors that influence your teaching of this idea.									
Teaching procedures (and particular reasons for using these to engage with this idea).									
Specific ways of ascertaining students' understanding or confusion around this idea (include likely range of responses).									

Figure 3.1: CoRe template

CoRe prompts for lesson unit (Loughran et al., 2006)

APPENDIX B: STEBI INSTRUMENT

Science Teaching Efficacy Belief Instrument*

Please indicate the degree to which you agree or disagree with each statement below by circling the appropriate letters to the right of each statement.

SA = Strongly Agree
A = Agree
UN = Uncertain
D = Disagree
SD = Strongly Disagree

1. When a student does better than usual in science, it is often because the teacher exerted a little extra effort.	SA A UN D SD
2. I am continually finding better ways to teach science.	SA A UN D SD
3. Even when I try very hard, I don't teach science as well as I do most subjects.	SA A UN D SD
4. When the science grades of students improve, it is most often due to their teacher having found a more effective teaching approach.	SA A UN D SD
5. I know the steps necessary to teach science concepts effectively.	SA A UN D SD
6. I am not very effective in monitoring science experiments.	SA A UN D SD
7. If students are underachieving in science, it is most likely due to ineffective science teaching.	SA A UN D SD
8. I generally teach science ineffectively.	SA A UN D SD
9. The inadequacy of a student's science background can be overcome by good teaching.	SA A UN D SD
10. The low science achievement of some students cannot generally be blamed on their teachers.	SA A UN D SD
11. When a low achieving child progresses in science, it is usually due to extra attention given by the teacher.	SA A UN D SD
12. I understand science concepts well enough to be effective in teaching elementary science.	SA A UN D SD
13. Increased effort in science teaching produces little change in some students' science achievement.	SA A UN D SD
14. The teacher is generally responsible for the achievement of students in science.	SA A UN D SD
15. Students' achievement in science is directly related to their teacher's effectiveness in science teaching.	SA A UN D SD
16. If parents comment that their child is showing more interest in science at school, it is probably due to the performance of the child's teacher.	SA A UN D SD
17. I find it difficult to explain to students why science experiments work.	SA A UN D SD
18. I am typically able to answer students' science questions.	SA A UN D SD
19. I wonder if I have the necessary skills to teach science.	SA A UN D SD
20. Effectiveness in science teaching has little influence on the achievement of students with low motivation.	SA A UN D SD
21. Given a choice, I would not invite the principal to evaluate my science teaching.	SA A UN D SD
22. When a student has difficulty understanding a science concept, I am usually at a loss as to how to help the student understand it better.	SA A UN D SD
23. When teaching science, I usually welcome student questions.	SA A UN D SD
24. I don't know what to do to turn students on to science.	SA A UN D SD
25. Even teachers with good science teaching abilities cannot help some kids learn science.	SA A UN D SD

*In Riggs, I., & Knochs, L. (1990). Towards the development of an elementary teacher's science teaching efficacy belief instrument. *Science Education, 74*, 625-637.

APPENDIX C: CONSENT FORM

Consent for Participation in Research

Title: The Role of Teacher Efficacy in the Development of Pedagogical Content Knowledge

Introduction

The purpose of this form is to provide you information that may affect your decision as to whether or not to participate in this research study. The person performing the research will answer any of your questions. Read the information below and ask any questions you might have before deciding whether or not to take part. If you decide to be involved in this study, this form will be used to record your consent.

Purpose of the Study

You have been asked to participate in a research study about teacher knowledge. The purpose of this study is centered on the interrelationship between Pedagogical Content Knowledge (PCK), defined as the knowledge needed to teach effectively, and teacher efficacy and how this association helps cultivate the development of the teacher knowledge base.

What will you to be asked to do?

If you agree to participate in this study, you will be asked to:

1. Take part in semi-structured teacher interviews that will last approximately 1 hour structured throughout the classroom observation phase of the study (approximately twice weekly)
2. Complete a 25 question Likert-based teacher efficacy survey during each semi-structured teacher interviews (approximately 15 minutes for each survey, to be taken twice weekly)
3. Approximate time commitment will be 2 to 3 hours per week during the study

This study will take about one calendar month during the fall semester of the 2013-2014 school year and will include approximately three study participants.

Your participation will be audio recorded.

What are the risks involved in this study?

There are no foreseeable risks to participating in this study.

What are the possible benefits of this study?

You will receive no direct benefit from participating in this study; however this study will help aid in developing better more effective teacher professional development programs.

Do you have to participate?

No, your participation is voluntary. You may decide not to participate at all or, if you start the study, you may withdraw at any time. Withdrawal or refusing to participate will not affect your relationship with The University of Texas at Austin (University) in anyway.

If you would like to participate please complete the consent form and return to the primary researcher. You will receive a copy of this form.

Will there be any compensation?

You will not receive any type of payment participating in this study.

What are my confidentiality or privacy protections when participating in this research study?

This study will be completely confidential. For the entire study, identities will be protected by using pseudonyms for people and places (will be used from the very start of the study). At no point in the study will actual names be mentioned or used.

If you choose to participate in this study, you will be audio and video recorded. Any audio and video recordings will be stored securely and only the research team will have access to the recordings. Recordings will be kept for 5 years and then erased. The data resulting from your participation may be used for future research or be made available to other researchers for research purposes not detailed within this consent form. However, any data that is shared will not contain any identifying formation.

Whom to contact with questions about the study?

Prior, during or after your participation you can contact the researcher Soon W. Han via email at soonhan@utexas.edu.

This study has been reviewed and approved by The University Institutional Review Board and the study number is 2013-06-0004.

Whom to contact with questions concerning your rights as a research participant?

For questions about your rights or any dissatisfaction with any part of this study, you can contact, anonymously if you wish, the Institutional Review Board by phone at (512) 471-8871 or email at orsc@uts.cc.utexas.edu.

Participation

If you agree to participate please return the completed form to the primary researcher.

Signature

You have been informed about this study's purpose, procedures, possible benefits and risks, and you have received a copy of this form. You have been given the opportunity to ask questions before you sign, and you have been told that you can ask other questions at any time. You voluntarily agree to participate in this study. By signing this form, you are not waiving any of your legal rights.

____
Printed Name

____________________________________ ___________________
Signature Date

As a representative of this study, I have explained the purpose, procedures, benefits, and the risks involved in this research study.

____
Print Name of Person obtaining consent

APPENDIX D: PARENTAL CONSENT FORM

Parental Permission for Children Participation in Research

Title: The Role of Teacher Efficacy in the Development of Pedagogical Content Knowledge

Introduction

The purpose of this form is to provide you (as the parent of a prospective research study participant) information that may affect your decision as to whether or not to let your child participate in this research study. The person performing the research will describe the study to you and answer all your questions. Read the information below and ask any questions you might have before deciding whether or not to give your permission for your child to take part. If you decide to let your child be involved in this study, this form will be used to record your permission.

Purpose of the Study

If you agree, your child will be asked to participate in a research study about teacher knowledge. The purpose of this study is centered on the interrelationship between Pedagogical Content Knowledge (PCK), defined as the knowledge needed to teach effectively, and teacher efficacy and how this association helps cultivate the development of teacher knowledge.

What is my child going to be asked to do?

If you allow your child to participate in this study, they will be asked to go about their usual classroom routine. Your child will be observed only without interference. This study will take about one calendar month during the fall semester of the 2013-2014 school year and will include approximately three participating teachers and their students. Your child will be audio recorded.

What are the risks involved in this study?

There are no foreseeable risks to participating in this study.

What are the possible benefits of this study?

Your child will receive no direct benefit from participating in this study; however, this study will help aid in developing better more effective teacher professional development programs.

Does my child have to participate?

No, your child's participation in this study is voluntary. Your child may decline to participate or to withdraw from participation at any time. Withdrawal or refusing to participate will not affect their relationship with The University of Texas at Austin

(University) in anyway. You can agree to allow your child to be in the study now and change your mind later without any penalty.

What if my child does not want to participate?

In addition to your permission, your child must agree to participate in the study. If you child does not want to participate they will not be included in the study and there will be no penalty. If your child initially agrees to be in the study they can change their mind later without any penalty. If, however, if you or your child does not wish to participate in the study, the following protocol will be used to insure your child is not part of the study: audio editing software (i.e. Audacity) will be used to block out any sound of your child.

Will there be any compensation?

Neither you nor your child will receive any type of payment participating in this study.

What are the confidentiality or privacy protections for my child's participation in this research study?

This study will be completely confidential. For the entire study, identities will be protected by using pseudonyms for people and places (will be used from the very start of the study). At no point in the study will actual names be mentioned or used. If you choose to participate in this study, your child will be video recorded. Any video recordings will be stored securely and only the research team will have access to the recordings. Recordings will be kept for 5 years and then erased. The data resulting from your participation may be used for future research or be made available to other researchers for research purposes not detailed within this consent form. However, any data that is shared will not contain any identifying formation.

Whom to contact with questions about the study?

Prior, during or after your participation you can contact the researcher Soon W. Han via email at soonhan@utexas.edu**.** This study has been reviewed and approved by The University Institutional Review Board and the study number is 2013-06-0004.

Whom to contact with questions concerning your rights as a research participant?

For questions about your rights or any dissatisfaction with any part of this study, you can contact, anonymously if you wish, the Institutional Review Board by phone at (512) 471-8871 or email at orsc@uts.cc.utexas.edu.

Signature

You are making a decision about allowing your child to participate in this study. Your signature below indicates that you have read the information provided above and have decided to allow them to participate in the study. If you later decide that you wish to withdraw your permission for your child to participate in the study you may discontinue his or her participation at any time. You will be given a copy of this document.

____
Printed Name of Child

_________________________________ _________________
Signature of Parent(s) or Legal Guardian Date

_________________________________ _________________
Signature of Investigator Date

APPENDIX E: ASSENT FORM

Assent for Participation in Research

Title: The Role of Teacher Efficacy in the Development of Pedagogical Content Knowledge

Introduction

You have been asked to be in a research study about teacher knowledge. This study was explained to your parents/guardian and they said that you could be in it if you want to. We are doing this study to help determine how teachers develop.

What am I going to be asked to do?

If you agree to be in this study, you will be asked to go about your daily routine in class. Nothing will be asked for you to do. This study will take place about twice weekly for about 1 month during your science class and there will be two other science classes that will be part of this study.

You will be audio recorded. The IRB may audit study records at any time.

What are the risks involved in this study?

There are no foreseeable risks to participating in this study.

Do I have to participate?

No, participation is voluntary. You should only be in the study if you want to. You can even decide you want to be in the study now, and change your mind later. No one will be upset.

If you would like to participate please sign this form and return it to your teacher. You will receive a copy of this form so if you want to you can look at it later.

Will I get anything to participate?

You will not receive any type of payment participating in this study.

Who will know about my participation in this research study?

The records of this study will be kept private. Your responses may be used for a future study by these researchers or other researchers.

Whom to contact with questions about the study?

Prior, during or after your participation contact the researcher Soon W. Han via email at soonhan@utexas.edu. for any questions or if you feel that you have been harmed.

Signature

Writing your name on this page means that the page was read by or to you and that you agree to be in the study. If you have any questions before, after or during the study, ask the person in charge. If you decide to quit the study, all you have to do is tell the person in charge.

______________________________	____________________
Signature of Participant	Date

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